UNIVERSIDADE DE LISBOA
FACULDADE DE CIÊNCIAS
DEPARTAMENTO DE ENGENHARIA GEOGRÁFICA, GEOFÍSICA E ENERGIA

Morocco towards a low-carbon economy: the role of energy efficiency, renewable energy and carbon capture and storage

Rita da Penha Gonçalves Pereira Machado

Mestrado em Engenharia da Energia e do Ambiente

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Abstract

To meet global energy demand both fossil and non-fossil energy sources will be required in the foreseeable future. The continued large-scale and widespread consumption of fossil fuels and in particular coal for power generation is necessary to sustain population and economic growth. Amongst a spectrum of measures, Carbon Capture and Storage (CCS) technologies have the potential to play a key role, in response to climate change, by decarbonizing on a large scale the energy and other industrial sectors.

This thesis has been developed in the context of the COMET project, which is funded under the Seventh Framework Program. The COMET project goal is to assess the techno-economic feasibility of integrating carbon dioxide transport and storage infrastructures in the West Mediterranean area. This project jointly coordinated by Portugal, Spain and Morocco considers several development scenarios for these countries energy systems within the time period 2010-2050. These scenarios include the location and development of the energy related and industrial major CO_2 point sources and the available potential for geological storage in those countries. The long-term scenarios of the Portuguese, Spanish and Moroccan energy systems are to be modelled and evaluated through the technical economic MARKAL/TIMES models.

As part of the COMET project, this thesis presents the quantitative and qualitative input data needed to model the energy system of Morocco via MARKAL/TIMES. The input data includes, among others: energy conversion, consumption and CO_2 emissions trends of the energy sector and other industrial activities; the identification of the installed capacity and future perspectives; an assessment of the energy end-use sectors; an estimation of the domestic energy related resources; and an assessment of relevant energy policies as MARKAL/TIMES is well suited to evaluate the global impact of these policies within the energy sector.

Key-words: CCS technologies, Energy System, Morocco, COMET

Resumo

As fontes de energia renovável não são, e não serão, num futuro próximo, suficientes para suprir as necessidades globais de energia e por isso os combustíveis fosseis irão continuar a ser utilizados em larga escala. De facto, o contínuo consumo dos recursos fósseis e, em particular, do carvão, para a geração de electricidade será necessário para sustentar o crescimento económico e populacional. Para fazer face às alterações climáticas, as tecnologias de captura e armazenamento de CO_2, apresentam-se como uma opção para reduzir significativamente as emissões de CO_2 para a atmosfera, associadas ao sistema electro-produtor e a outros processos industriais.

Esta dissertação foi desenvolvida no âmbito do projecto COMET, financiado pelo Sétimo Programa-Quadro. O objectivo do projecto COMET é estudar a viabilidade técnico-económica da integração de uma estrutura de transporte e armazenamento de CO_2 na zona oeste do Mediterrâneo. Este projecto coordenado por Portugal, Espanha e Marrocos considera vários cenários dos sistemas energéticos destes países para o período 2010-2050. Estes cenários incluem a localização e desenvolvimento das pricipais unidades emissoras de CO_2 e o potencial de armazenamento geológico nos países envolvidos. Os cenários dos sistemas energéticos dos três países serão modelados recorrendo aos modelos MARKAL/TIMES.

Como parte integrante do projecto COMET, este trabalho apresenta a informação quantitativa e qualitativa para modelar o sistema energético de Marrocos via MARKAL/TIMES. Esta informação inclui: dados relativos à transformação, consumo e emissões de CO_2 associadas ao sector enérgico e industrial; a identificação da capacidade instalada e perspectivas futuras; uma análise dos sectores consumidores finais de energia; uma estimativa dos recursos energéticos domésticos; e um levantamento das políticas relacionadas com o sector energético, uma vez que os modelos MARKAL/TIMES têm a capacidade de avaliar o impacto dessas políticas nesse sector. Esta dissertação apresenta também alguns dos resultados obtidos através da modelação e uma análise dos mesmos.

Palavras-chave: Captura e Armazenamento de CO2, Sistema Energético, Morrocos, COMET

List of Abbreviations and Acronyms

ADEREE - National Agency for Development of Renewable Energy and Energy Efficiency
AfDB - African Development Bank
bpd - Barrels per day
CCGT - Combined Cycle Gas Turbine
CCS - Carbon Capture and Storage
CDER - Centre de Développement des Energies Renouvelables
CDM - Clean Development Mechanism
CED - Detroit Wind Energy Company
CHP - Combined Heat and Power
CO_2 – Carbon Dioxide
COMELEC - Comité Maghrébin de l'Electricité
COMET – Integrated infrastructure for CO_2 transport and storage in the west MEdiTerranean
CSP - Concentrated Solar Power
CtL – Coal-to-Liquid
Dh – Dirham, Morocco's official currency
EE – Energy Efficiency
EET - Tahaddart Electricity Company
EOR – Enhanced Oil Recovery
ESP – Electrostatic Precipitators
EU - European Union
FCC – Fluidized Catalytic Cracker
FGD – Flue Gas Desulphurization
FWP - Seventh Framework Program
GDP - Gross Domestic Product
GEF - Global Environment Facility
GHG – Greenhouse Gas
GIS - Geographic Information System
GtL - Gas-to-Liquid
GVA - Gross Value Added
GWh – Gigawatt hour
h - hour
H_2 – Hydrogen
ha – hectare
HV – High Voltage
IAEA - International Atomic Energy Agency
IGCC – Integrated Gasification Combined-cycle
IMF – International Monetary Fund
ISCC - Solar Combined Cycle Power Plant
JLEC - Jorf Lasfar Energy Company
km – kilometer
km^2 – square kilometer
ktoe - kilotonne of oil equivalent
kton – kiloton
kV - kilovolt
kW - kilowatt
kWh – kilowatt hour
LHV – Lower Heating Value
LNG – Liquefied Natural Gas
LPG - Liquefied Petroleum Gas
m – meter
m^2 – square meter
MAD - Moroccan Dirhams
MASEN - Moroccan Agency for Solar Energy
MENA - Middle East and North Africa
METRAGAZ - The Maghreb-Europe Gas Pipeline Management Company
Mt - Megatonne
MW - Megawatt
MWh – Megawatt hour
NGCC – Natural Gas Combined-cycle
NIHD - National Initiative for Human Development
NO_x – Nitrous Oxide
OC – Other Countries
OCP - Office Chérifien des Phosphates
OECD - Organization for Economic Co-operation and Development
OECD+ - OECD Countries, plus EU Countries not in the OECD
OME – Other Major Economies
ONE - National Office of Electricity
ONHYM - National Office of Hydrocarbons and Mining
PC - Pulverized Coal
PCE - Production Concessionnel d'Electricité
PM10 – Particulate Matter of less than 10 micron diameter
PNAP - National Plan of Priority Actions
ppp – Purchasing power parities
PV - Photovoltaic
RE – Renewable Energy
RES - Renewable Energy Sources
s - second
SAMIR - The Moroccan Refining Company
SCNR – Selective Noncatalytic Reduction
SCR – Selective Catalytic Reduction
SIE - Société d'Investissements Energétiques
SO_2 - Sulfur Dioxide
t - tonne
TFC – Total Final Consumption
tkm - tonne-kilometre
toe – tonne of oil equivalent
TPES - Total Primary Energy Supply
UNFCCC - United Nations Framework Convention on Climate Change
VHV – Very High Voltage
WEO – World Energy Outlook
yr – year

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1 Introduction

This thesis has been developed in the context of the COMET project. COMET project aims to study the techno-economic feasibility of integrating carbon dioxide transport and storage infrastructures in the West Mediterranean area and it involves Portugal, Spain and Morocco. This project considers several development scenarios for those countries energy systems within the time period 2010-2050 and takes into account the location and development of the energy related and industrial major CO2 emission sources as well as the available potential for geological storage in those countries. These countries long-term energy systems scenarios are to be modelled and evaluated through the technical economic models MARKAL/TIMES.

As part of COMET project this thesis presents the quantitative and qualitative input data to model the energy system of Morocco via MARKAL/TIMES. The input data includes, among others: energy transformation, consumption and CO_2 emissions' trends of the energy sector and other industrial activities; the identification of the installed capacity and future perspectives; an assessment of the energy end-use sectors; an estimation of the national energy resources; and an assessment of relevant energy related policies as MARKAL/TIMES is well suited to evaluate the global impact of policies within the energy sector. This thesis includes an analysis of the first modelling outcomes.

The present work is divided in nine chapters. Chapter two summarizes the past and present status of the Energy Sector in a global perspective. It introduces the problematic of energy related GHG emissions and climate change and includes IEA energy scenarios for the next decades. The potential and main characteristics of the key climate change mitigation options are also reviewed in this chapter. Chapter three overviews the CCS technologies process chain within its different options and applications. It summarizes the current status of the technologies in terms of projects, costs and regulatory and legal framework in a general approach. The fourth chapter presents the goals and motivations of COMET project, its structure and the thesis's role within the project itself. The fifth chapter presents the quantitative and qualitative information collected to model the energy system of Morocco via MARKAL/TIMES. Chapter six presents the final remarks. Chapter seven presents the conclusions of the thesis. Chapter eight identifies future work.

2 Global Energy Demand and Energy-related CO_2 Emissions

2.1 Energy Demand and Supply

Global energy demand has been steadily rising over the past several decades. Population and income growth are key driving forces behind the demand for energy (IEA, 2010). As the global energy demand upward trend is expected to continue in the coming decades, increasing uneasiness over energy security and environmental sustainability issues arise.

In 1971 the total primary energy supply (TPES) has been of 5533.5 Mtoe and, by 2008, it reached 12267.4 Mtoe, which means that within that period the TPES more than doubled (IEA 2010). Figure 2-1 presents the global population, real GDP using purchasing power parities (ppp) and TPES evolution within 1971 and 2008.

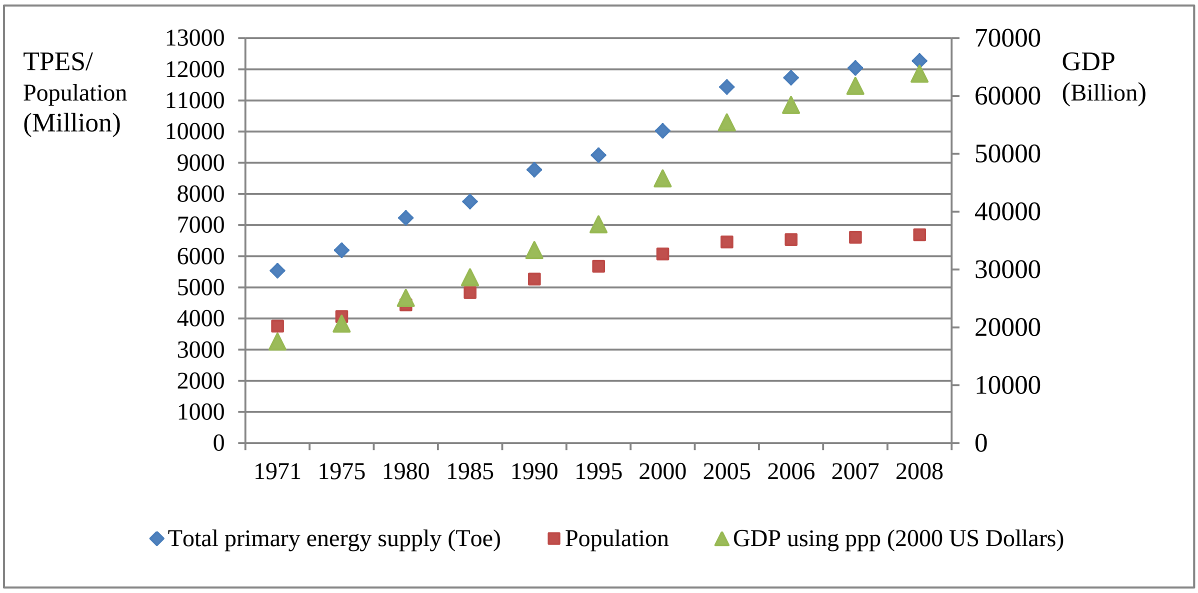

Figure 2-1 – Evolution of the global TPES, population and GDP using ppp (within 1971 and 2008) (IEA, 2010)

The global energy intensity - the amount of energy necessary to generate each unit of GDP - has decreased progressively over the last decades owing to several factors such as energy efficiency (EE) improvements, fuel switching and structural adjustments in the global economy away from energy-intensive industries (IEA, 2010b). If no improvements in energy intensity had been accomplished, global energy consumption would be much higher today (IEA, 2010b).

In 1980 and 2008 almost 85% and 81% of the global energy demand was supplied from fossil fuels. Table 2-1 presents the world primary energy demand by fuel in 1980 and 2008 (IEA, 2010b).

Table 2-1 – World primary energy demand by fuel (Mtoe) (IEA, 2010b)

	Oil	Coal	Gas	Nuclear	Hydro	Biomass and waste*	Other renewables	Total
2008	4059	3315	2596	712	276	1225	89	12271
1980	3107	1792	1234	186	148	749	12	7229

*Includes traditional and modern uses.

In 2009 the global economic recession induced the first energy consumption decline since 1982 which was mostly felt in OECD countries and in the territory of the Former Soviet Union, in line with its economies condition. In that year global oil consumption dropped 1.7%, representing the major decline since 1982. Coal consumption kept on fairly solid in 2009 representative of the minor annual change since 1999. In 2009 natural gas consumption registered the most rapid decline amongst fossil fuels and fell by 2.1%. In that year only hydroelectric and other renewable forms of energy registered an output growth. Hydroelectric generation has been the world's fastest-growing energy source in 2009. Fiscal incentive, in many countries, among other government encouragement measures, induced the global wind and solar generation capacity growth by 31% and 47% respectively. China and the US accounted for 62.4% of the whole wind generation growth (BP, 2010).

In 2010 driven by the economic recovery, global energy consumption grew by 5.6% which represented the largest increase in percentage terms since 1973. The growth in energy consumption has been felt worldwide: consumption in OECD countries grew by 3.5% and in non-OECD countries the energy consumption increased by 7.5% and was 63% beyond the 2000 totals. In that year, China energy consumption increased by 11.2% and became the world's largest energy consumer followed by the US (BP, 2011).

Energy prices development diverged. Oil prices rebounded worldwide (average oil prices for that year as a whole have been the 2nd highest in history), whereas natural gas and coal prices varied by region. Natural gas prices increased significantly in markets indexed to oil prices. Coal prices increased strongly in Europe but remained weak in Japan and North America (BP, 2011).

Accounting for 33.6% of global energy consumption, oil continued the world's most consumed fuel. After two succeeding years declining, global oil consumption increased 3.1% (reaching a record level of 87.4 million b/d). OECD consumption grew by 0.9%, the first grow after 2005. Beyond OECD, consumption evolution recorded a 5.5% growth. Growth persisted strong in China and Middle Eastern countries, with Chinese consumption rising by 10.4%. Even if 2010 has recorded the biggest percentage grow in oil consumption since 2004, it represents a minor global growth rate amongst fossil fuels (BP, 2011).

In 2010 coal accounted for 29.6% of global energy consumption and its consumption increased 7.6%, which represents the major overall growth since 2003. China accounted for nearly two-thirds of the global consumption growth. The coal consumption upsurge was also strong in OECD countries where consumption grew by 5.2%, the most solid growth since 1979 (BP, 2011).

The global natural gas consumption increased by 7.4% in 2010, which represents the fastest growth since 1984. Except in the Middle East, consumption growth was beyond average in all regions. The US had the world's largest rise in consumption in volumetric terms, growing by 5.6%. Russia and China both registered the largest volumetric increases in the country's history. Consumption in other Asian countries grew fast as well (10.7%), with India increasing its consumption by 21.5% (BP, 2011).

Worldwide, hydroelectric and nuclear production registered the biggest upsurge since 2004. Hydroelectric output increased by 5.3%. China was responsible for more than 60% of global hydroelectric growth owing to new capacity and wet weather. Global nuclear production increased by 2% with three-quarters of the growth coming from OECD economies. French nuclear production increased by 4.4%, which represented the major volumetric increase in the world. Globally, other renewable energy (RE) sources continued to grow rapidly. Biofuel production increased by 13.8% in that year and RE for power generation increased by 15.5%, owing to a steady growth in wind energy (22.7%) (BP, 2011).

2.1.1 Energy-related CO_2 Emissions

In 1995, the Intergovernmental Panel on Climate Change (IPCC), in its Second Assessment Report, concluded that there is a balance of evidence that suggests a discernible human influence on climate change (IPCC, 1995). Indeed, even if GHG such as CO_2, CH_4, and N_2O are constantly being emitted to the atmosphere through natural processes, over the last 250 years anthropogenic activities related emissions have significantly altered their atmospheric concentrations.

The CO_2 atmospheric concentration has risen from 280 ppm in the pre-industrial period to 390 ppm by the end of 2010 (IPCC, 2011). One other noteworthy fact is that atmospheric CO_2 concentration has increased by just 20 ppm over the 8000 proceeding years to industrialization whereas, since 1750, it has risen by more than 100 ppm. CO_2 is one of the most prevalent GHG, and within the latter GHG specified, CO_2 presents the highest radiative forcing (RF[1]) (IPCC, 2005).

Among the many human activities that emit CO_2, the energy sector represents by far the largest source of emissions and fossil-fuel combustion is a central issue within the climate change debate. Besides fossil-fuel combustion within the power and the transport sectors, there are several other processes that emit substantial quantities of CO_2. These, among others, include the following industrial intensive processes: cement, iron and steel, chemicals and petrochemicals, pulp and paper and aluminum manufacture (IEA, 2011h). Changes in land use and forestry practices may, as well, release significant amounts of CO_2 or act as a sink for CO_2.

Between 1971 and 2008, global CO_2 emissions from fuel combustion more than doubled, rising from 14096.3 to 29381.4 million ton. In 2008, global CO_2 emissions increased 0.4 Gt representing a growth rate of 1.5% comparatively to 2007 (IEA, 2010). In 2008, for the first time, the CO_2 emission levels of the Annex I countries dropped below 1990 levels and the aggregate emissions of the developing countries has been superior to those from the developed countries (IEA, 2010).

- **Global Energy Related CO_2 Emissions by Fuel**

Coal - the utmost carbon-intensive of fossil fuels with nearly twice the carbon content per unit of energy as that of natural gas - has been, during the last decade, the fastest-growing energy source and the rate of emissions from coal use has risen from 0.6% per year within 1990 and 2000 and 4.8% per year within 2000 and 2007 (IEA, 2010b1) (IEA, 2011). Figure 2-2 presents the global CO_2 emissions by fuel, within 1971 and 2008.

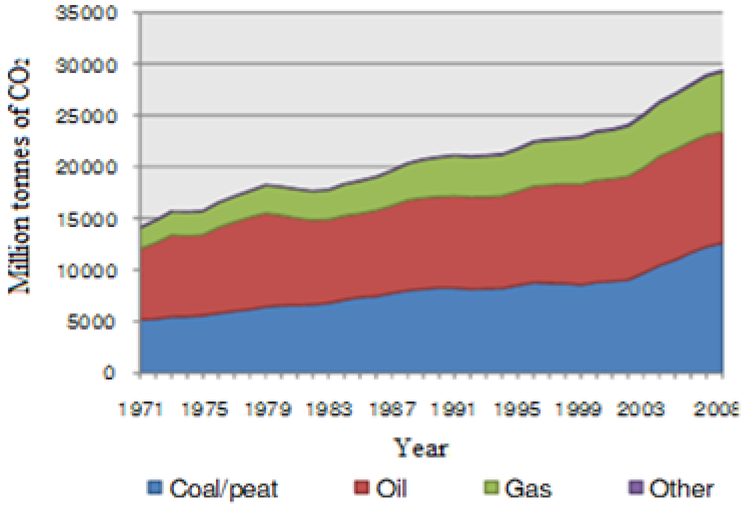

Figure 2-2 – Global CO_2 emissions by fuel (IEA, 2010)

This CO_2 coal related emissions upsurge over a relatively short period can be explained by the growing energy demand in coal based economies and by the intensification of coal-fired power generation in response to higher oil and gas prices (IEA, 2010b1). In 2010, 44% of the estimated CO_2 emissions came from coal, 36% from oil and 20% from natural gas (IEA, 2011k).

[1] RF is a concept used for quantitative comparisons of the strength of different human and natural agents that trigger climate change.

The environmental concerns related to the use of coal comprise not only the associated CO_2 emissions and the implications of those for Climate Change but, among others: the emission of other gases and particulates produced within the combustion process such as NO_x, SO_2 and toxic trace elements and the disposal of ash and spoil from processes associated with the mining of coal in the air, water and land.

- **Energy Related CO_2 Emissions by Sector**

In 2008, within the energy system, the power and heat generation sector was categorically the major producer of CO_2 emissions, being responsible for 41% of the CO_2 emissions (Figure 2-4). In that year the electricity generation sector emitted 11 Gt of CO_2. In 2008, the combined share of the power and heat generation and the transport sectors accounted for two-thirds of the CO_2 emissions. The transport and the manufacturing industries and constructions sectors accounted for 23% and 20% respectively of the CO_2 emissions in 2008 (IEA, 2010). Figure 2-3 presents the increasing share of the electricity and heat sectors on total energy related CO_2 emissions.

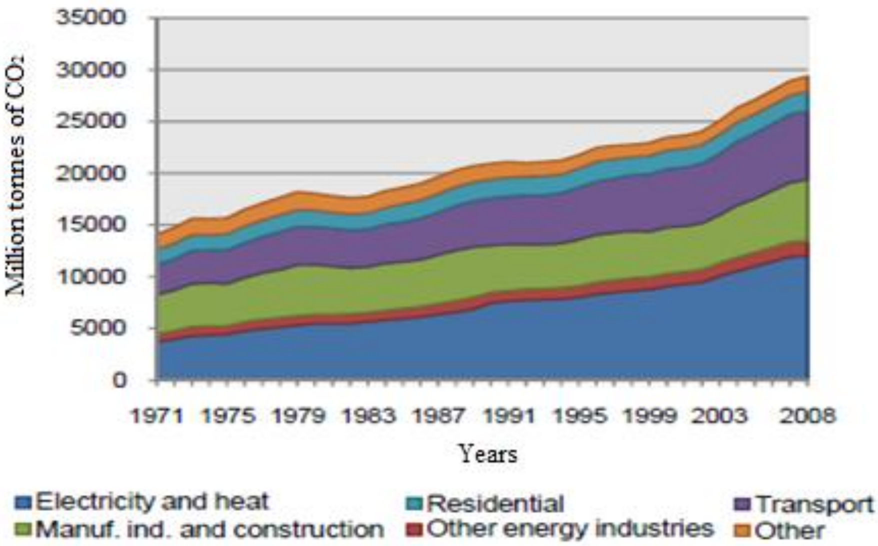

Figure 2-3 – CO_2 emissions by sector (IEA, 2010)

Generally, the power generation sector relies deeply on coal (IEA, 2010) (IEA, 2010b). Coal is crucial for global energy security, it is abundantly available, with sufficient supplies for more than 150 years, affordable, reliable and, easy and safe to transport (IEA, 2010b) (IEA, 2011a). In 1990 the global share of coal for power generation has been approximately 37%. In 2008, 41% of the global power generation came from coal, 21% from gas, 16% from hydro and 14% from nuclear (Table 2-2) (IEA, 2010b). Countries such as Australia, China, India, Poland and South Africa generate between 69% and 94% of their electricity and heat through coal combustion (IEA, 2010). Table 2-2 presents the global electricity generation by source in 1990 and 2008.

Table 2-2 – World electricity generation (TWh) (IEA, 2010b)

	1990	2008
Total generation	11821	20183
Coal	4427	8273
Oil	1338	1104
Gas	1726	4303
Nuclear	2013	2731
Hydro	2145	3208

	1990	2008
Biomass and waste	131	267
Wind	4	219
Geothermal	36	65
Solar PV	0	12
CSP	1	1
Marine	1	1

By 2008 almost two-thirds of the global coal demand was for power sector consumption and another one-fifth for industrial sector use (IEA, 2010b). Since 1990 the share of coal in the power sector has grown by 10 percentage points while the share in industrial energy use has declined slightly (IEA, 2010b).

Decreasing CO_2 emissions from coal-fired plants is a central concern within multiple proposals for mitigating GHG emissions. Options include capturing and sequestering the CO_2 emitted from the coal plants, and increasing substituting coal-fired generation for other power sources such as wind or nuclear power. Another option is to replace coal power with increased use of natural gas generation since gas fired power using modern generating technology releases less than half of the CO_2 per MWh as of a coal-fired power plant (CRS, 2010). In fact, a typical 500 MW coal-fired power plant will emit around 400 tonnes of CO_2/h, whereas a modern natural gas-fired combined cycle (NGCC) plant of the same size will emit about 180 tonnes of CO_2/h in the flue gases (CSFL, 2010).

2.1.2 Energy-related Past Trends Problematic

Even if in the past decade:

- There has been a substantial rise in investment in RE worldwide; solar PV and wind power have achieved considerable deployment;
- The rate of EE development in OECD countries has begun to speed up again, after many years of modest gains;
- Major car companies were adding hybrid and full-electric vehicles to their product lines and many governments had launched plans to encourage consumers to buy these vehicles; and
- Public investment for RD&D in low-carbon technology reached an all-time high in 2009 (2011, IEA);

in 2010, according to the IEA, the energy-related CO_2 emissions reached the highest level in history and the present energy use and CO_2 emissions trends run directly counter to the constant warnings sent by the United Nations IPCC (IEA, 2011k) (IEA, 2010b1).

2.2 Global Energy Scenarios and Climate Change

The increasing demand of energy is considered a global multifaceted issue with ever rising complexity. It involves not just the question of whether the expected rise in energy demand can be met, but also whether this demand can be met sustainably, which mix of energy sources is optimal, and whether there may also be means to reduce demand without compromising the global economy.

The IPCC stated that only scenarios resulting in a 50% to 80% reduction of global CO_2 emissions by 2050, compared to 2000 levels, can limit the long-term global mean temperature rise within 2.0ºC to 2.4ºC.

In December 2009 heads of state met for the 15^{th} Conference of Parties of the United Nations Framework Convention on Climate Change (UNFCCC) in Copenhagen. The resulting Copenhagen Accord, to which all major emitting countries and many others associated themselves, established a non-binding goal of restraining the long-term average increase in the global temperature to 2ºC above pre-industrial levels. Major emerging-market and developing countries undertook abatement pledges for the first time. The 2ºC goal has been further recognized as critical in the United Nations Climate Change Conference, held in Cancun, in 2010.

Even if the GHG in the atmosphere long-term stabilisation at 450 ppm by no means guarantees that the temperature increase will be limited to 2°C, targeting a 450 ppm of CO_2 equivalent concentration is often acknowledged as equivalent to the 2°C objective.

For strategic analysis and long-term planning many energy scenarios are continually being reported by either national or international organizations such as the IEA, the U.S. Department of Energy (DOE), the European Commission and the World Energy Council (WEC). All these organizations state that in the time frame of 2020-2030, worldwide energy demand will rise, keeping pace with population and economic growth in developing countries.

- **IEA Scenarios**

The 2010 edition of the World Energy Outlook (WEO), published by the IEA, provides energy demand and supply, updated projections until 2030 through three scenarios based on several different assumptions.

Its central scenario, entitled the New Policies Scenario (NPS), takes into account the general policy strategies and commitments that have been announced by numerous countries worldwide, in order to restrict the greenhouse effect and address energy security concerns, even where the measures to implement these commitments have yet to be identified or announced. The potential impacts of the implementation of those policy commitments on energy markets can be weighed, by comparing them with the projections from the Current Policies Scenario (CPS) in which no change in policies as of mid-2010 is assumed to be implemented. The third scenario, the 450 Scenario, sets out an energy pathway consistent with the target agreed at the UN climate meeting in Copenhagen in December 2009 to limit the increase in global temperature to 2ºC above pre-industrial levels. This scenario assumes the implementation of the high-end of national pledges and tougher policies after 2020 including the nearly entire elimination of fossil fuel consumption subsidies (globally) to achieve the objective of limiting the concentration of GHG in the atmosphere to 450 parts per million of CO_2 equivalent (IEA, 2010b).

All three IEA scenarios have the same assumptions about population growth. Global population is projected to grow from an estimated 6.7 billion in 2008 to around 8.5 billion in 2030 – an average rate of increase of nearly 1% per year. Most of the increase in global population will occur in non-OECD countries, particularly in Asia and Africa. In fact, these countries population is estimated to increase from 5.5 billion in 2008 to 7.2 billion in 2035 corresponding to an average annual growth rate of 1%. In the OECD countries, most of the population growth is expected in North America. Projections suggest that the OECD population will increase by 0.4% annually, between 2008 and 2035 (IEA, 2010b).

All three IEA scenarios have the same assumptions regarding economic growth as well. The three scenarios projections are extremely sensitive to the GDP growth rate estimations since energy demand tends to rise in line with GDP, yet usually at a lower rate (IEA, 2010b). The 2010 edition of the WEO assumes that within the 2008-2035 time period the world economy grows on average by 4.4% per year. OECD countries GDP annual growth is expected to reach 1.8% and non-OECD countries GDP is expected to grow by 4.6% per year over the same projection period.

- **Global Energy Demand**

For the 2008 to 2035 period the energy demand projections from the three WEO 2010 scenarios differ considerably. In the NPS global energy demand is projected to increase by 1.2% annually reaching 16750 Mtoe by 2035. In the CPS, global energy demand is estimated to increase on a higher rate, by 1.4% per year, reaching 18048 Mtoe by 2035. At a comparatively lower rate, in the 450 Scenario, the global energy demand grows by 1.7% annually reaching 14920 Mtoe by 2035 (Figure 2-6) (Energy prices warrant that projected supply and demand are in balance during the Outlook period in all scenarios) (IEA, 2010b).

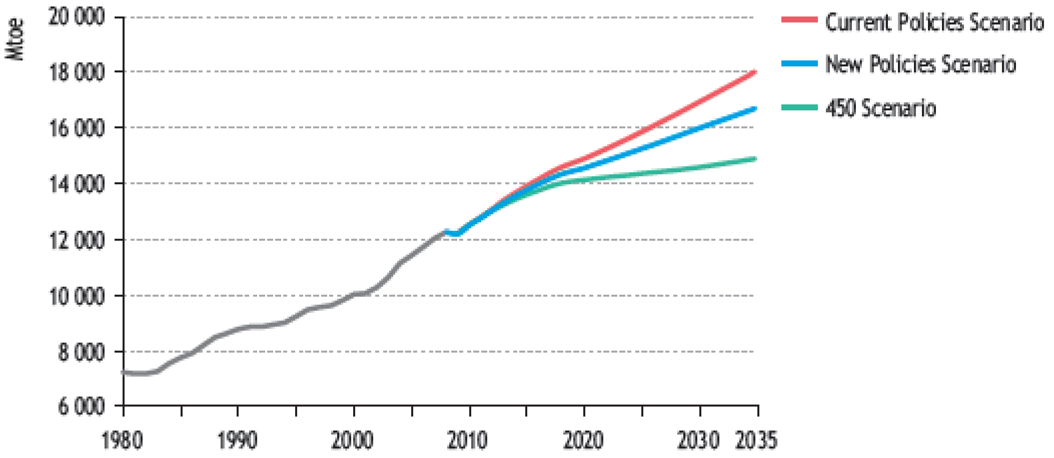

Figure 2-4 – World primary energy demand by scenario (IEA, 2010b)

The policies that are assumed to be brought together in the NPS and 450 Scenario have a noteworthy impact on the energy intensity rate decline over the projection period. In the CPS, the energy intensity declines as well, but at an inferior rate. Compared to 2008, by 2035 the energy intensity declines 28% in the CPS, 34% in the NPS and 41% in the 450 Scenario (IEA, 2010b).

By 2035 in all three scenarios, fossil fuels keep on being the dominant primary energy sources altough their share on the overall primary fuel mix differs significantly. By 2035 the fossil fuels share projections from the NPS, the CPS and the 450 Scenario are 74%, 79% and 62% respectively. The renewables and nuclear share projections are considerably higher in the 450 Scenario (Table 2-3) (IEA, 2010b).

Table 2-3 – World primary energy demand by fuel and scenario (Mtoe) (IEA, 2010b)

	NPS		CPS		450 Scenario	
	2020	2035	2020	2035	2020	2035
Coal	3966	3943	4307	5281	3743	2496
Oil	4346	4662	4443	5026	4175	3816
Gas	3132	3748	3166	4039	2960	2985
Nuclear	968	1273	915	1081	1003	1676
Hydro	376	476	364	439	383	519
Biomass and waste*	1501	1957	1461	1715	1539	2316
Other renewables	268	699	239	468	325	1112
Total	14556	16748	14896	18048	14127	14920

* Includes traditional and modern uses.

- **Energy-related CO_2 Emissions**

According to the IEA, in order to embark into a trajectory that is compatible with the long-term stabilisation of the atmospheric concentration at 450 ppm CO_2-eq, energy-related emissions need to fall to 21.7 Gt CO_2 by 2035 (IEA, 2010b).

Energy Related CO_2 Emissions in the NPS

Under the assumptions of the NPS, energy related emissions in the OECD countries peak before 2015 and decay to 11.8 Gt in 2020, 7% above 1990 levels. Supposing that OECD countries intensify domestic reduction efforts after 2020, OECD emissions gradually decline to 10 Gt in 2035. In non-

OECD countries, energy-related CO_2 emissions are projected to jump from 15.7 Gt in 2008 to 20.8 Gt by 2020 and 24 Gt by 2035 (IEA, 2010b).

In 2008, coal has been responsible for the largest share on total CO_2 emissions, followed by oil and gas. In the NPS this order remains identical by 2035. Still, the share of coal decreases to 41% and that of oil to 36%, while the share of gas extends to 24%. In 2008 emissions from bunker fuels accounted for 3.5% and by 2035 its share increases to 4.0% (IEA, 2010b).

Even though the projection for GHG emissions in the NPS represents a clear improvement on current trends (emissions in the CPS reach 35.4 Gt in 2020 and continue to increase across the projected period), between 2008 and 2035, global energy related CO_2 emissions increase by 21%, from 29.3 Gt to 35.4 Gt precluding the 450 ppm CO_2 eq target. The NPS places the world in a path consistent with stabilising the concentration of GHG at just over 650 ppm CO_2-eq, resulting in an estimated temperature rise of over 3.5ºC above pre-industrial levels in the long term (IEA, 2010b).

Energy Related CO_2 Emissions in the 450 Scenario

The 450 Scenario sets a path consistent with the long-term stabilisation of the atmospheric concentration at 450 ppm of CO_2 equivalent (emissions in the 450 Scenario reach 31.9 Gt in 2020 and decline to 21.7 Gt in 3035). The GHG atmospheric concentration in the 450 Scenario reaches a highest at some 520 ppm CO_2-eq around 2040 before declining back to 450 ppm CO_2-eq by around 2150. This scenario points out the most economical way of meeting the climate goals, presenting, given the current policy context, the scale of action required to do so (IEA, 2010b).

In order to decarbonise the energy economy so drastically, the commitment of all countries to impose tougher supplementary and complementary abatement policies and measures as of 2020 is mandatory (IEA, 2010b).

The elimination and reduction of subsidies on fossil fuels accounts for 1.4 Gt of CO_2 emissions avoidances in 2035 compared with the CPS. Substantial spending on energy efficiency and low-carbon technologies in order to achieve the 450 Scenario is required, and further spending in the 2010-2035 period extends to $18 trillion compared with the CPS and $13.5 trillion compared with the NPS (IEA, 2010b).

- **Global energy related CO_2 emission savings by policy measure – IEA 450 Scenario**

Atmospheric emissions avoidances in the 450 Scenario, comparatively to the CPS, amount to 3.5 Gt in 2020 and to 20.9 Gt in 2035. The IEA identifies the most cost-effective portfolio of technologies to attain the latter emission reductions targets. The share of the different measures to be taken in pursuit of the 450 Scenario abatement commitments varies over time. Once low-cost options are exhausted, other expensive options have to be applied (Figure 2-7) (IEA, 2010b).

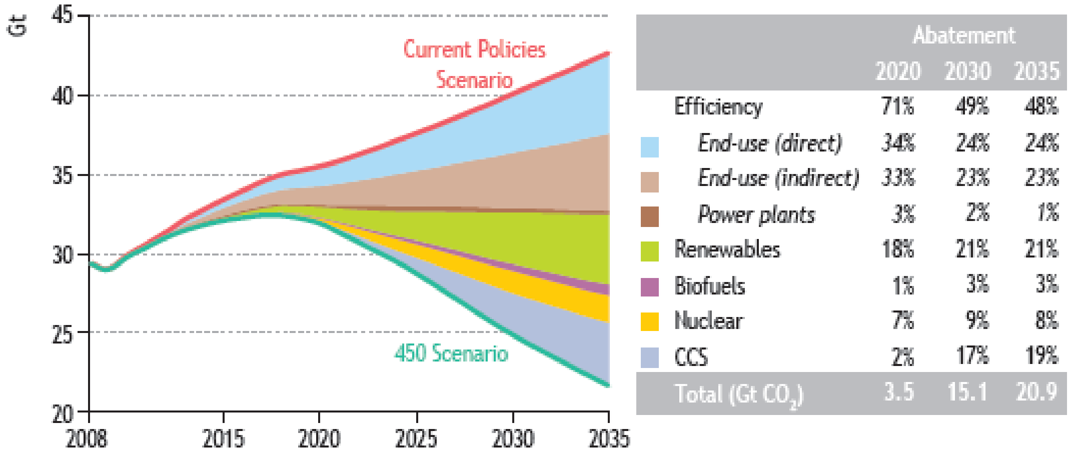

Figure 2-5 – World energy-related CO_2 emissions savings by policy measure in the 450 Scenario (IEA, 2010b)

Under the assumptions of the IEA 450 Scenario, the end-use efficiency share on the total CO_2 abatement compared to the CPS is 67% by 2020 (when total abetment is of 3.5 Gt CO_2). Whereas, by 2035, at the time when total CO_2 abatement target amounts to 20.9 Gt (in relation to the CPS), the CO_2 abatement share of the end-use efficiency decreases to 47%. The CO_2 price plays a critical role in EE developments (IEA, 2010b).

As long as support policies that go beyond the impact of the price of CO_2 are established, RE deployment together with biofuels, account for a rising share of CO_2 savings throughout the projection timeframe, increasing from 19% in 2020 to 24% in 2035. Nuclear power share on CO_2 abatement by the end of the projection period amounts to 8% (IEA, 2010b).

Within the projection period CCS becomes a critical abatement technology and by 2035 it accounts for nearly one-fifth of the total CO_2 abatement target. In this scenario, CCS is deployed in new coal and gas-fired power plants after 2020 in OECD+[2] and Other Major Economies[3] and is broadly used as a retrofit measure as well. CCS also becomes a fundamental abatement alternative in some emissions intensive industrial sectors, such as cement, iron and steel, chemicals, and pulp and paper, as well as in energy transformation processes such as coal-to-liquids (IEA, 2010b).

According to the IEA, decarbonizing the power sector is of crucial importance to make deep cuts on CO_2 emissions and even though fossil fuels keep on being the dominant fuels on the primary energy mix in the 450 Scenario, the power sector is considerably decarbonised by 2035, especially in developed countries, and over three-quarters of global electricity generation is low-carbon (IEA, 2010b). This low carbon target entails an intensive low-carbon technologies deployment in order to displace inefficient thermal plants, and to meet the growth in electricity demand, while keeping an affordable and secure service to consumers (Table 2-4) (IEA, 2010b).

Table 2-4 – Capacity additions by fuel and region in the 450 Scenario (GW) (IEA, 2010b)

	2010-2020				2021-2035			
	World	OECD+	OME	OC	World	OECD+	OME	OC
Coal	576	91	356	127	438	140	236	62
CCS-equipped*	13	9	3	1	408	188	213	8
Oil	31	6	17	8	35	9	13	12
Gas	434	148	186	100	480	168	215	97

[2] OECD+ includes all OECD countries plus non-OECD EU countries.
[3] OME comprise Brazil, China, the Middle East and South Africa.

	2010-2020				2021-2035			
CCS-equiped*	4	4	1	0	173	104	69	1
Nuclear	137	46	75	16	387	165	145	77
Hydro	364	60	192	113	497	65	167	265
Biomass	73	44	17	12	234	80	89	65
Wind-onshore	430	245	150	35	840	381	302	157
Wind-offshore	67	42	20	4	298	170	91	36
Solar PV	123	81	21	21	652	238	233	181
Concentrating solar power	39	18	11	9	185	75	68	42
Geothermal	12	5	1	5	35	13	7	15
Marine	1	1	-	0	19	17	1	1
Total	2285	787	1047	451	4100	1522	1568	1010

* CCS-equipped capacity additions in the table may exceed the overall additions of the corresponding fuels as this table includes plant retrofit.

- **CCS deployment – 450 Scenario Requirements**

By 2030, in comparison with the 450 Scenario published within the 2009 WEO, CCS in the 2010 IEA 450 Scenario plays a further significant role in emission reduction (to the extent of 1.2 Gt more). In the latter Scenario, CCS retrofit plays a larger role, particularly in China and the United States (IEA, 2010b). This degree of CCS deployment involves a supplementary investement of $1.3 trillion of that within the CPS in the 2010 to 2035 period, representing nearly 8% of the total investment required to achieve the 450 Scenario path. A large number of CCS projects take place in OECD+ countries, as the price of CO_2 in the power and industry sectors certifies it as feasible options subsequently to a period between 2010 and 2020 in which government investments to fund CCS demonstration projects amount to an average annual of $3.5 to $4 billion (IEA, 2010b).

Shortly after 2020, subsequently the introduction of a CO_2 price, CCS deployment extents to Other Major Economies as well. By 2035, in OECD+, CCS technologies account for 25% of abatement or 1.6 Gt of CO_2 and in Other Major Economies accounts for 21% of abatement or 2 Gt of CO_2 (IEA, 2010b).

In order to achive this sum of abatement, extended international co-operation and financing for CCS demonstration in developing countries is necessary, possibly through the Clean Development Mechanism (CDM) or an alternative financing mechanism generating offset credits. The implementation of legal and regulatory frameworks and systematic mapping of storage sites is also necessary (IEA, 2010b).

The benefits and main characteristics of EE, RES and Nuclear energy are briefly overviewed within the following section. In the succeeding chapter, CCS technologies will be discussed in further detail in the context of the dissertation.

2.3 Energy Efficiency

Benefits of Energy Efficiency

Energy Efficiency (EE) was first considered by some surveyed companies as early as 1970 and the average date for setting EE targets was 1998 (Hoffman, A.J., 2007). The history of EE is intimately bound up with the notions of progress, growth and power. Indeed, there is a continuous race between EE and economic growth. If the latter is faster than the rate of EE increase, then total energy consumption increases, as it has been historically (Boyle G., 2003).

EE improvement is recognised by the International Community as an essential cost-effective requirement to address energy sustainability concerns and to serve multiple proposes, such as:

- Enhance energy security (reduce domestic demand and imported energy to maximize exports, increase reliability and control energy demand growth);

- Boost economic development and competitiveness (reduce energy intensity, improve industrial competitiveness, reduce production costs and achieve more affordable energy customer costs);
- Reduce climate change (contribute to global mitigation and adaption efforts, meet international obligations under the UNFCCC);
- Improve public health (reduce indoor and local pollution) (IEA, 2010c).

Even if the global energy intensity has improved, at an average rate of 1.7% per year, since the early 1970s, this enhancement must be measured against overall increases in energy consumption and CO_2 emissions resulting from population and economic growth (IEA, 2011).

EE improvements can be pursued in all conversion and end-use processes in the energy system and EE can and should be enhanced worldwide, within all the different sectors (IEA, 2011).

Energy Efficiency opportunities by Sector

Decarbonizing the power and heat sector is critical in order to achieve deep CO_2 emissions cuts and one of the most important near-term approaches for reducing CO_2 emissions from fossil-fired power generation is to improve the efficiency of new and existing plants. There are several solutions for maximizing EE within the power and heat generation sector, for instance, through the adoption of the best available technologies and the upgrading or replacement of older inefficient plants. This, along with EE improvements within power transmission and distribution would result in important fossil fuel savings and CO_2 emissions reduction and consequently increase the sustainability of the overall energy sector.

Pursuing EE improvements within residential, commercial and public-service buildings is also an issue of major importance since buildings account for close to 40% of energy used in most countries (IEA site). The energy use in this sector includes space heating and cooling, water heating, lighting, appliances and cooking and business equipment (IEA, 2010b). Presently, space heating and cooling as well as hot water are estimated to account for approximately half of global energy consumption in buildings (IEA, 2011d). The largest technical potential for energy savings in residential, commercial and public-service buildings consists on EE building design, implemented together with efficient heating and cooling systems/equipment. For users and owners of buildings in general, EE measures are most often feasible, as savings pay for the additional investment costs over time. Within OECD and economies in transition, the low retirement rate of buildings and the relatively modest extension, implies that most of the energy savings potential involves retrofitting and purchasing new technologies for the prevailing building stock. In developing countries instead, where the construction expansion of new building is expected, opportunities exist to secure significant energy savings through improved EE standards for new buildings (IEA, 2010d).

As regards the industrial sector, it has achieved considerable EE improvements in the last decades, but this progress pales beside the increased industrial production worldwide (IEA, 2010d). In fact, this sector is currently responsible for about one third of all the energy used worldwide and for almost 40% of global CO_2 emissions. Therefore, reducing the CO_2 intensity of the most widely produced commodities such as cement, iron and steel, chemicals and petrochemicals, paper and paperboard and aluminium by decoupling energy consumption from output via enhancing EE within the industrial facilities and processes, and moving to best available technologies is necessary to reduce environmental problems (IEA, 2011e).

As to the transport sector, it is the second-largest CO_2 emitter followed by industry and buildings (IEA, 2010b) and the highest energy final consumer and it is forecasted to remain so if no EE improvements and additional measures are pursued. Accomplishing deep cuts in CO_2 emissions in this sector will hinge on decelerating the increase in fuel transport use, by greater EE improvements and raising the share of low-carbon fuels (IEA, 2010d). In 2008 the IEA published EE recommendations for the transport sector. These have focused on road transport and policies on improving EE of tires, fuel economy standards for both light-duty vehicles and heavy-duty vehicles, and eco-driving. Fiscal measures were not incorporated in the current IEA transport EE recommendations. However, financial incentives or penalties would promote the purchase of more EE vehicles and therefore accelerate the deployment of EE technologies.

Barriers to Energy Efficiency further deployment

Abundant cost-effective EE potential is considered to be unexploited and EE can and should be enhanced across all sectors. Still, many EE projects with strong financial rates of returns remain unimplemented worldwide, but principally in developing and emerging countries. Indeed, despite the potential benefits, realizing EE improvements can be blocked by the following barriers:

- Market: market organisation and price distortions impede customers from appraising the true value of EE; split incentive problems created when investors cannot capture the benefits of improved efficiency; transaction costs (projections development costs are high relative to energy savings);
- Financial: up-front costs and dispersed benefits discourage investors; perception of EE investments as complex and risky, with high transaction costs; lack of awareness of financial benefits on the part of financial institutions;
- Information and awareness: lack of necessary information and understanding, on the consumers side, to make rational consumption and investment decisions);
- Regulatory and institutional: energy tariffs that discourage EE investment; incentive structures encourage energy providers to sell energy rather than invest in cost-effective EE, institutional bias towards supply-side investments;
- Technical: privation of affordable EE technologies suitable to local conditions; unsatisfactory capacity to identify, develop, implement and maintain EE investments (IEA, 2010c).

Policies to support Energy Efficiency

In order to address the previously mentioned barriers to EE development, several governments at all levels have, over the years, introduced different policies, such as:

- Pricing mechanisms: variable tariffs where higher consumption levels invoke higher unit prices;
- Regulatory and control mechanisms: compulsory activities, such as energy audits and energy management, minimum energy performance standards, energy consumption reduction targets, EE investment obligations on private companies;
- Fiscal measures and tax incentives: grants, subsidies and tax incentives for EE investments, direct procurement of EE goods and services;
- Promotional and market transformation mechanisms: public information campaigns and promotions, inclusion of EE in school curricula, appliance labelling and building certification;
- Technology development: development and demonstration of EE technologies;
- Commercial development and capacity building: creation of energy service companies, training programmes, development of EE industry;
- Financial remediation: revolving funds for EE investments, project preparation facilities, contingent financing facilities (IEA, 2010c).

2.4 Renewable Energy

Benefits of Renewable Energy

The Renewable Energy (RE) potential is wide and can supply a large portion of energy demand. RE sources derive directly or indirectly from natural processes connected to sunlight, heat stored in the earth or gravitional forces and are continuously, naturally replenished (IEA, 2011f). The array of benefits arising from the greater development and deployment of RE - within a portfolio of low-carbon and cost-competitive energy technologies capable of responding to the emerging major challenges of climate change, energy security, and access to energy - is well acknowledged and it has become a priority for both governments of IEA member countries and emerging economies. Indeed, more than 70 governments around the world, including all IEA members, have already introduced targets and policies to support the deployment of RE technologies (IEA, 2011g).

Overview of the main RES characteristics

Solar

Solar energy is categorically the most abundant energy resource available on earth. At the time there are three main technologies to harness the solar energy: solar photovoltaic (PV) and concentrating solar power (CSP) to provide electricity, and solar thermal collectors for heating and cooling (IEA, 2010b).

PV systems are commercially available technologies that transform direct and diffused solar radiation into electricity, by means of a photovoltaic process, using semi-conductor devices. PV systems can be deployed anywhere in the world on apposite land and on houses. PV technology is very modular and can be installed close to centres of demand. These technologies are, as well proper for off-grid electrification. As solar PV is a variable source of power, its integration into the grid may be challenging for system operators where it is used on a large scale. Conversely, peak production takes place during the day, usually matching, in hot regions, with peak electricity demand, often driven by air conditioning loads (IEA, 2010b).

CSP is a proven technology that produces high-temperature heat for electricity generation or for co-generation of electricity and heat. CSP systems are only able to convert direct normal irradiation. Therefore, suitable areas for CSP deployment are those with strong sunshine and clear skies, frequently arid or semi-arid areas. CSP technology opens up the prospect of thermal energy storage and hybrid designs, for instance, with natural gas co-firing. If equipped with adequate storage capacity, CSP systems could provide base-load power (IEA, 2010b).

Solar thermal collectors produce heat from solar radiation, by heating a fluid that circulates through a collector. Similar to PV panels, these systems are able to convert both direct and diffuse light and for that reason can be installed anywhere in the world. The collectors produce comparatively low temperature heat, apposite for space heating and hot water production in buildings and some lower temperature industrial applications. Since solar thermal heat is not always available when needed, solar thermal collectors are relatively inapt to replace other sources of heat, at least until inter-seasonal storage becomes affordable. The potential of these technologies for industrial proposes is almost unexploited for the moment (IEA, 2010b).

Wind power

The kinetic energy of wind is converted in wind turbines into electricity. Suitable wind speeds for electricity generation (from 4 m/s to 25 m/s) are virtually attainable all over the world, with the exception of certain equatorial areas. Wind power is converted onshore and off-shore, where typically wind speeds are higher and the wind is available for longer periods of time. The distance from centres of demand onshore and water depth are key aspects for the deployment of these technologies off-shore. Similar to solar, wind is a variable source of power and the output increases and drops as wind strength fluctuates. Therefore, integrating wind power into grids, particularly once wind becomes a major component of the total system, is challenging (IEA, 2010b).

Hydropower

Hydropower uses the potential energy of water and converts it into electricity, either in run-of-river plants or reservoirs. Hydropower is the most mature renewable energy technology and can be explored almost all over world. In the OECD countries the most suitable areas, particularly for large hydro, have been explored by now, but there is still potential for small-scale developments unexploited. Significant potential for hydro generation still exists in Asia, Latin America and Africa.

Some hydro plants can be operated as base load, while others serve as peaking plants, depending on the volume of the reservoirs and the electrical capacity of the dam relative to the total system; hydropower plants can be operated flexibly, particularly where pumped storage is available, and hence are capable to supply sudden fluctuations in power demand (IEA, 2010b).

Biomass

Biomass energy is produced from any organic material, of plant and animal origin, derived from agriculture and forestry production and resulting by-products, and industrial and urban wastes (OECD, 2004). The type of technologies exploiting biomass resources is very varied and the selection of technology depends on both the final use and on the nature of the biomass feedstock (IEA, 2010b).

The potential of this resource can be assessed, based on the land availability for dedicated crops and the availability forestry and agricultural residues and waste. The availability of land for crops and water use are major concerns of biomass exploitation (IEA, 2010b).

Geothermal energy

Geothermal energy is the energy available as heat contained in or discharged from the earth’s crust that can be exploited for power generation or for direct heat within a number of applications such as: space and district heating, water heating, aquaculture and industrial processes. Moderate or high temperatures geothermal resources are suitable for power generation. High-temperature geothermal resources usually exist in areas near plate boundaries or rift zones. If the temperature level is too low for power production, geothermal heat resources can be exploited for direct use in district heating systems and for some industrial and agricultural purposes, where local markets exist. Some of the positive features of this resource include the capability to provide base load power, the compatibility with both centralized and distributed energy generation; sources of low temperature geothermal heat exist in all over the world. The high capital cost, and the fact that exploited geothermal reservoirs require continuous management are some of the barriers for further exploitation of this resource (IEA, 2010b).

Marine power

Marine energy technologies use the kinetic energy of tides, waves and currents of the sea, as well as temperature and salinity gradients, for the power generation. The technologies to exploit this resource are the least developed of the renewable energy technologies. This marine energy resource is, in principle, limitless and can be found in all world regions, but in practice it is only viable at sites close to demand centres and where, simultaneously, damage to local ecosystems can be controlled. Some marine technologies such as those that exploit tides have variable output, but on the other hand they are predictable (IEA, 2010b).

RE share in the TPES

During the last decade, the policy support for RE has increased considerably, mainly due to the necessity to reduce the GHG emission, to diversify the supply mix and to reduce the dependence on imported fossil fuels. Between 2000 and 2008 the total primary renewable energy supply grew from 1319 Mtoe to 1590 Mtoe (IEA, 2010b).

Biomass is currently the most exploited source of RE. In 2008 biomass use amounted to 1225 Mtoe, most of which was exploited in developing countries, in traditional ways by around 2.7 billion people. The use of modern biomass (refers to all biomass with the exception of traditional biomass, which refers to the biomass consumption within the residential sector in developing countries and includes the use of charcoal, agricultural residues and animal dung for cooling and heating) is lesser (amounted to 478 Mtoe in 2008), but is rapidly increasing, mainly for electricity generation and as feedstock for making transport fuels. Hydropower is, currently, the second largest RE source in primary energy demand (accounted for 276 Mtoe in 2008) and the dominant source of renewables-based electricity. Solar, wind, geothermal and marine power have been developing rapidly in recent years, but their total share within primary energy supplies is still modest (IEA, 2010b).

Electricity generation based on RE augmented by almost a third from 2000 to 2008. However, in absolute terms, this increase is offset by the escalation of fossil fuels based power generation (IEA, 2010b).

In the OECD region, electricity generation based on RE increased more than that based on coal within the same period, but much less than natural gas generation whereas, in non-OECD countries the increase in electricity generation based on RE was slightly lower than the corresponding increase from gas, but much lower than that from coal (IEA, 2010b).

In 2008 RE supplied almost 3800 TWh worldwide, 19% of total electricity production. Globally, electricity based on RE increased by approximately 900 TWh. Even if this upsurge is mainly attributable to hydropower (responsible for 85% of RE based electricity in 2008), new forms of RE grew very quickly, particularly wind power, which expanded seven-fold. During the same period, solar PV electricity generation grew 16-fold. Biomass and geothermal power both increased as well, but at a modest pace, while marine power and CSP are just now starting to take-off (IEA, 2010b).

As government policies to support renewables tend to focus more on electricity and transport, the development of RE for heat production at the point of use (and heat from district heating systems) was much more modest. Despite efforts to increase the access to modern fuels for underprivileged, the use of traditional biomass has increased since 2000 (IEA, 2010b).

Biofuels are supplying a growing share of transport fuels and the global use of biofuels, consumed almost entirely within road transport, increased five-fold in the 2000 to 2008 period, reaching 1 mb/d and supplying almost 3% of total fuel demand in road transport. In 2009, biofuels use continued increase, as production capacity expanded (encouraged in most countries by government support), whereas oil demand for road transport decreased (for the first time since 1980) owing to higher prices and reduced economic activity (IEA, 2010b).

Barriers to RE further deployment

Despite progress, many challenges still need to be overcome in order to sustain the necessary growth of RE. Currently, most of the RE technologies are not able to compete with conventional ones since these are comparatively less capital-intensive. Therefore, it is of decisive importance to improve the policy framework for RE in order to bridge the competitiveness gap between RE and traditional alternative energy technologies. A continuous effort in research, development and deployment for RE technologies is also necessary to increase productivity and decrease costs (IEA, 2011f).

The expansion of renewables raises significant system integration issues that must be taken into account. Some options and technologies, including smart grids, exist so as to increase the flexibility of electricity systems and to allow the integration of greater shares of variable renewable electricity (IEA, 2011f).

2.5 Nuclear Power

The nuclear power was first demonstrated in the 1950s and in the early 1960s the first commercial nuclear power plants entered operation. Within the 1970s and 1980s, nuclear power capacity raised speedily as nations sought to decrease fossil fuel dependence, particularly after the 1970s oil crisis (IEA, 2010f).

Benefits of Nuclear Power

Nuclear power presents the potential to play an important role for decarbonizing the power sector and enhance energy security since it has the capability to deliver substantial amounts of very low carbon baseload electricity at costs stable over time (IEA, 2010e). Indeed, the indirect emissions of nuclear power plants are at least of an order of magnitude below the emissions of fossil fuels (NEA, 2009).

Nuclear energy is at a very different stage of technological development and deployment than most other low-carbon energy options and is considered an established mature technology as a result of over 50 years of development and operational experience. The newest projects for nuclear power plants, now under consideration, integrate the knowledge acquired over the years as well as the recent technological developments to enhance safety and performance (IEA, 2010f). Still, further development of reactor and fuel cycle technologies will be important if nuclear energy is to achieve its full potential.

Barriers for Nuclear Power further deployment

The barriers to a wider nuclear deployment in the short to medium term are predominantly policy, industrial and financial-related. In the long term, the potential of nuclear power will depend in uranium resources availability (IPCC, 2007).

The construction of a nuclear power plant involves a large capital investment (IEA, 2010f). Governments aiming to increase nuclear capacity are required to provide support for financing new nuclear construction. When in operation a nuclear power plant entails comparatively small and predictable fuel, operating and maintenance costs which means that nuclear plants have low marginal costs of production, but require several years to recover their capital costs (IEA, 2010f). This intensifies the risks of electricity and carbon markets uncertainty and implies that a sustained government policy support is a prerequisite for a successful nuclear programme.

The technical complexity of construction and operation of a nuclear power plant also represents a significant downside (IEA, 2010f).

Even if concerns about security of energy supply and climate change have tended, in recent years to increase the general recognition of the benefits of nuclear energy, several factors weaken public support in many countries. These include concerns about nuclear safety, radioactive waste management and disposal, and the potential proliferation of nuclear weapons.

In the operation of nuclear power plants, safety should always be the principal consideration, not only in terms of technical or ageing issues, but also in terms of management system and qualified workforce related issues. Application of an integrated management system and structured workforce planning are needed throughout the plant life in order to guarantee effective plant organization and management. Plant operators and regulators must always make sure that plant safety is preserved and, where possible, enhanced during its operating lifetime.

Nuclear power in the TPES

In the 1990s, with the exception of Japan and Korea, nuclear growth stagnated worldwide (IEA, 2010f). Reasons for this involved safety concerns subsequent to the Three Mile Island and Chernobyl accidents, delays and higher costs than expected at some nuclear plants, and a return to inferior fossil fuel prices (IEA, 2010f).

Within recent years nuclear power progression has remained nearly flat with global operational installed capacity going from 370 GW at the end of 2005 to 375 GW by the end of 2010 (IEA, 2010f) (IEA, 2011). This modest growth reflects the low number of new projects construction realized during the past two decades. Still, most large energy consuming countries have, in recent years, at least considered a nuclear program to meet future energy needs. However, the March 2011 major accident within the Fukushima Daiichi nuclear power plant in Japan that resulted from a severe earthquake and tsunami, led many countries to review the safety of their existing and planned nuclear plants projects. This tragic event real impact on nuclear installed capacity development is currently uncertain (IEA, 2011).

Nuclear fusion

Energy from the fusion of heavy hydrogen fuel is actively being pursued as a long-term almost inexhaustible, environmentally benign, supply of energy. The scientific feasibility of fusion energy has been proven but technical feasibility remains to be demonstrated (IPCC, 2007). Fusion scientists from the European Union, India, China, Japan, Korea, Russia and the United States are now proceeding with the construction of a 500MW experimental thermal power plant (IEA, 2011k).

3 CCS technologies

As discussed in the preceding item, the degree to which CCS may contribute to the reduction of GHG emissions, globally and in specific countries in the coming decades, depends on the interplay of many factors including the character of climate change objectives, the further development of CCS technology, the relative costs and benefits of alternative abatement approaches, and explicit political and policy choices.

However, and as demonstrated in the previous chapter, one thing is certain: CCS technologies have the potential to play a crucial role in the world's response to climate change, by decarbonizing on large scale the energy sector and other industrial activities. As such, together with EE and RE, CCS features in all of the IEA carbon abatement scenarios.

Even if the benefits of CCS are well acknowledged, as a result of its complex nature, CCS technologies still face substantial technical, legal, regulatory, environmental, public acceptance, and economic barriers to its widespread deployment (ICF, 2010).

CCS Process Chain

CCS entails a number of technologies and consists of the separation of the CO_2 from large point sources, the transportation of the CO_2 to a storage location and its long-term isolation from the atmosphere.

Large point sources of CO_2 consist of, among others, large fossil fuel or biomass energy facilities, major CO_2 emitting industries, natural gas production, synthetic fuel plants and fossil fuel based H_2 production plants (IPCC, 2005).

Depending on the process application, there are three major approaches for capturing the CO_2 within the above mentioned facilities: post-combustion, pre-combustion and oxyfuel combustion.

The CO_2 captured, after compression (or liquefation) may, potentially, be transported (generally via pipeline) for storage in geological formations (such as oil and gas fields, unminable coal beds and deep saline formations[4]), in the ocean (direct release into the ocean water column or onto the deep seafloor), in mineral carbonates[5], or for use in industrial processes (IPCC, 2005).

The purpose of the following paragraphs is to provide an overview of the CCS technologies process chain and its possible applications.

3.1 CO_2 Capture

The goal of CO_2 capture technologies is to achieve a concentrated stream of CO_2 prepared to be transported to a storage site. Indeed, the implementation of CO_2 capture technologies, within most industrial activities that make use of boilers, turbines, iron and steel furnaces or cement kilns, requires a step to convert a relatively dilute stream of CO_2 to a higher concentration so as to allow economic transportation and storage. In the above mentioned applications, concentrations of CO_2 in exhaust gas streams range from around 3-20% CO_2, which typically need to be concentrated to >85% prior to compression, transport and storage.

[4] Saline formations are sedimentary rocks saturated with formation waters containing high concentrations of dissolved salts. They are widespread and contain enormous quantities of water that are unsuitable for agriculture or human consumption. Because the use of geothermal energy is likely to increase, potential geothermal areas may not be suitable for CO_2 storage.

[5] Storage of CO_2 as mineral carbonates does not cover deep geological carbonation or ocean storage with enhanced carbonate neutralization.

CO_2 capture technologies have been recurrently used in some industrial processes such as natural gas production, where CO_2 is removed from the natural gas stream, during processing, to achieve specific natural gas quality standards. Similar procedures occur in plants that produce ammonia or H_2 for process purposes (IPCC, 2005). However, within the power sector, capturing CO_2 is still an emerging technology (not demonstrated on a commercial scale).

As previously mentioned, there are three main technologies available for capturing the CO_2 from power plants and other industrial facilities:

- Post-combustion - technologies that separate the CO_2 from the flue gases produced by the combustion of a primary fuel (coal, natural gas, oil or biomass) with air (process described in section 3.1.1);
- Oxy-fuel combustion - technologies that replace air for O_2 in combustion, in order to produce a flue gas that is mainly composed of H_2O and CO_2 which may be readily captured (process described in section 3.1.2); and
- Pre-combustion - technologies that process the primary fuel in a reactor to produce separate streams of CO_2 and H_2 (process described in section 3.1.3) (IPCC, 2005).

Each of the above approaches involves the separation of CO_2 from a gas stream and there are five main methods available for doing so, depending on the CO_2 (i.e. concentration, pressure, volume) to be captured:

- Chemical solvent scrubbing;
- Physical solvent scrubbing;
- Adsorption/desorption;
- Membrane separation;
- Cryogenic separation (GCI, 2011).

Chemical/Physical Absorption

CO_2 capture systems may be based on chemical absorption (using sovents such as MEA, Monoethanolamine), or on physical absorption (using solvents such as Selexol, Dimethylether of polyethylene glycol) (IEA, 2004). Once the CO_2 is scrubbed from the raw gas, the saturated solution must be regenerated and the CO_2 extracted. The bonding energy, between the solvent and CO_2, involved in physical absorption is lower than that of chemical absorption, which is an advantage when it comes to regeneration. Chemical absorption processes involve a heat induced CO_2 recovery, whereas physical absorption processes involve pressure induced CO_2 recovery (IEA, 2004). Chemical absorption is considered a better option at low CO_2 concentration because its energy use is not particularly sensitive at low concentrations and low partial pressures of CO_2. Phsyical absorption is the preferred option at higher CO_2 concentrations and at higher partial pressures (IEA, 2004). These methods are industrially established capture techniques.

Adsorption/desorption

Adsorption is a physical process that involves the attachment of a gas or liquid to a solid surface. The regeneration of the adsorbent may be achieved by the application of heat (temperature swing adsorption, TSA) the reduction of pressure (pressure swing adsorption, PSA) or by a mix process of pressure and temperature swing adsorption (PTSA) (Wang, et al. 2010) (RECCS, 2008). Adsorbents which can be applied to CO_2 capture include activated carbon, alumina, metallic oxides and zeolites (Wang, et al. 2010). Current adsorption systems may not be suitable for application in large-scale power plant flue gas treatment. At such scale, the low adsorption capacity of most available adsorbents may pose significant challenges. In addition, the flue gas streams to be treated must have high CO_2 concentrations because of the generally low selectivity of most available adsorbents (Wang, et al. 2010).

Membrane Separation

In a membrane based separation, selectivity is provided by the membranes themselves. Membranes include polymeric materials, metals or ceramics. Efficient separation demands high selectivity, a large membrane surface and high permeability for the desired gas components in comparison with the other gases in the mixture. This method is currently under development and is not yet state of the art. Today membranes are used for gas separation on a small scale. They are especially efficient for separating gases with very different sized molecules (RECCS, 2008).

Cryogenic Distillation (Separation)

By cooling at pressures as low as 4-5 bar, CO_2 can be condensed out of gas mixtures. The gas mixture must be previously dried. This physical process is suitable for treating flue gas streams with high CO_2 concentrations considering the costs of refrigeration (RECCS, 2008). The procedure is energy-intensive, particularly when the concentration of CO_2 is low. But capture and compression for transport are accomplished in a sole stage. By now this method is used for conditioning biogas, but no experience has yet been gathered in the power station sector (RECCS, 2008). This technique is frequently associated to oxy-fuel CO_2 capture processes (process described in section 3.1.2).

Within the following section the post-combustion, oxy-fuel capture and pre-combustion techniques are briefly revised.

3.1.1 Post-combustion CO_2 Capture

In this process, the CO_2 is captured from a flue gas at low pressure (1 bar) and low CO_2 content (3-20%), in general (Le Thiez, P. 2005). Post-combustion capture technologies may be applied, in concept, to the flue gases from the combustion of all types of fuel. Still, the fuel impurities are decisive in the design and costing of the complete plant. The separation task is to remove CO_2 from a mixture of mainly nitrogen and O_2 (Le Thiez, P. 2005). There are several options for separating the CO_2 from this gas mixture by post-combustion CO_2 capture techniques. Nonetheless, several assessment comparative studies suggest that, currently, the absorption process based on chemical solvents is the most suitable option for post-combustion CO_2 capture and absorption practices are now commercially available for post-combustion CO_2 capture systems, although not yet on the necessary scale for power plant flue gases (IPCC, 2005).

In a power plant, with an absorption-based CO_2 capture process the flue gas is to be brought into contact with a chemical absorbent inside a scrubber column. Flue gases to the CO_2 absorber must be cooled to improve the absorption of CO_2 and minimize solvent losses due to evaporation (Wang, et al. 2010).

Typical absorbents that are used today are amines and carbonates. Amines are able to capture CO_2 from streams with a low CO_2 partial pressure and form water soluble compounds. Thus, amine-based systems are able to recover CO_2 from the flue gas of conventional pulverized coal (PC) fired power plants, however only at a significant cost and efficiency penalty (Figueroa, et al. 2007). On the other hand Carbonate systems are based on the capacity of a soluble carbonate to react with CO_2 and form bicarbonate, which when heated, releases CO_2 and reverts to a carbonate. An advantage of carbonates over amine-based systems is the significantly lower energy required for regeneration (Figueroa, et al. 2007).

Preceding the absorption process, other acid gases such as SO_2 and NO_2 need to be removed as they diminish the performance of the system by forming heat stable salts with solvent such as MEA. SO_2 removal is frequently attained in a Flue Gas Desulphurization (FGD) unit. SO_2 concentrations of less than 10 ppm are recommended. NO_x is removed by Selective Catalytic Reduction (SCR), Selective Noncatalytic Reduction (SCNR) or low NO_x burners. Particulate matter such as fly ash needs to be removed by electrostatic precipitators (ESP) or bag house filters otherwise they would cause foaming in the absorber and regenerator columns reducing their performance (Wang, et al. 2010).

After the absorption process, the absorbent and the CO_2 are separated in a regeneration column (the CO_2 loaded absorbent is heated which has the effect of both freeing the CO_2 and also cleaning the absorbent to allow it to be re-used). The result is then a stream of pure CO_2 and a second stream of absorbent that can be recycled to the scrubber column. By using this method, around 90% of the CO_2 is captured, with the CO_2 stream having a very high purity – of around 99% (EON, 2008).

The CO_2 is then dried to remove any excess water and then it is prepared for transportation and eventual storage (EON, 2008).

Although amine-based today is the most mature technology for post-combustion CO2 capture, ammonia-based solvents are considered a potentially attractive alternative (IEA, 2011b).

Alternatively post-combustion CO_2 capture can also be performed by adsorption instead of absorption or by a membrane module but today, absorption is the most mature technology.

A key advantage of this technology (post-combustion CO_2 capture method) is that it can be retrofitted to existing power stations and that it is already in use in a wide range of processes around the world Table 3-1.

Table 3-1 – Overview of the advantages and disadvantages of post-combustion CO_2 capture technologies (EON, 2011)

Strengths	Weaknesses
Good prospects for retrofiting	Reduces thermal efficiency and significantly increases operating costs
Robust process with only limited impact on plant availability	Capture equipment requires considerable additional space and cooling water
Significant potential for technical optimization	Large amounts of chemicals must be handled
Energy required for carbon capture can be offset by advances in the thermal efficiency of conventional generation	Only limited experience worldwide with capturing carbon from the flue gas of coal-fired plants
Flexible operating characteristics	
High degree of CO_2 purity (>99.5%)	
Commercial rollout likely by 2020	
Can be used in conventional power plants worldwide	
Several equipment suppliers conducting R&D	

3.1.2 Oxy-fuel CO_2 Capture

In this process the fuel combustion - coal, natural gas oil or biomass – occurs in either pure O_2 or a mixture of pure O_2 and a CO_2-rich recycled flue gas. The resulting flue gas contains mainly CO_2 and water vapour and excess O_2 (required assuring the fuel complete combustion). These two main components are easily separated through cooling, the water condenses and a CO_2 rich gas-stream is formed.

The great advantage of the oxy-fuel CO_2 capture technique is that a capture rate of 97% is possible, together with a purity of 99.9%. The purity of the CO_2 captured depends on the purity of the fuel and O_2 supplied the level of air in-leakage in the boiler, the process design and the intensity of purification (IEA, 2011b).

O_2 is the key requirement for any oxy-fuel combustion system (IPCC, 2005) and existing methods of O_2 production from air separation include cryogenic distillation, adsorption using multi-bed pressure swing units and polymeric membranes. These process economic aspects depend on the required O_2 quantities. For all the large applications, such as power station boilers, cryogenic air separation is the only economic viable solution (IPCC, 2005).

Even if oxy-fuel combustion technologies components are well established in the aluminium, iron and steel and glass melting industries today, oxy fuel combustion with CO_2 storage is currently in the demonstration phase. The world’s first pilot project to demonstrate oxyfuel technology at a coal-fired power plant was inaugurated (the Schwarze Pumpe project) in 2008. This pilot project in western Germany is owned by the European energy company, Vattenfall, and it is effectively demonstrating the capture of CO_2 emissions with a purity of over 99% (NGC, 2011).

Table 3-2 - Overview of the advantages and disadvantages of oxy-fuel combustion technologies (EON, 2011)

Strengths	Weaknesses
Incorporation known, commonly used technologies and process	Separation of air into pure O_2 and CO_2 scrubbing are energy intensive
Modification to power plants are primarily required on the flue gas side; the water and steam cycle remains unchanged	Comparatively low CO_2 purity; achieving higher levels of purity requires significantly more energy
No solvents needed	Development phase would require complete pilot and demonstration power plants
Comparatively little space required for additional equipment at power plant side	Limited operational flexibility

3.1.3 Pre-Combustion CO_2 Capture

With a pre-combustion technology, CO_2 is to be captured before the combustion of the fuel. In this process CO_2 is captured from a gas mixture with predominantly H_2 gas at high pressure and medium CO_2 content. Pre-combustion capture technologies can be applied to different feedstocks such as coal, natural gas, biomass and waste (IEA, 2008). This technique is currently in commercial operation for different applications such as H_2, ammonia and syngas production.

A pre-combustion capture system usually includes a first stage of reaction intended to produce a mixture of H_2 and CO (syngas) from a primary fuel (IPCC, 2005). This conversion can be done through gasification, partial oxidation or steam reforming technology. Gasification is most often used for solid fuels, partial oxidation for liquids, and steam reforming for gases (CCS 101).

The CO is then converted into CO_2 through a shift conversion process which also produces a stream of H_2. To separate the produced H_2 from the CO_2, the mixture undergoes a gas clean. This gas clean up step is frequently obtained using similar methods employed for post-combustion processes (for e.g.: chemical absorption with solvents including MEA, using heat induced CO_2 recovery, or physical absorption using solvents including Selexol with pressure induced CO_2 recovery), although there are advantages to removing the CO_2 from the syngas mainly associated with the pressure of the gas, which decreases compression energy requirements (CCC, 2010) (Stephens, J., 2005). The H_2 - a valuable by-product of pre-combustion – may, among other utilities, be used as a fuel for power generation (CCS 101)

Pre-combustion CO_2 capture technologies are particularly relevent for coal based plants with integrated gasification combined cycle (IGCC) as IGCC power plants can offer a low-cost high efficiency pre-combustion CO_2 capture platform (ADB, 2011).

Within an IGCC technology, before the syngas goes to the gas turbine to generate power, pre-combustion processes can be incorporated to separate and capture CO_2. However, CO_2 capture implementation to an IGCC power plant do not involve a simple end-of pipe modification since it implies not only the additional CO_2 capture equipment but changes in other components are also required. The syngas CO_2 remotion prior to combustion changes the composition of the gas to be burned, increasing the H_2 content, which alters the design requirements for the gas turbine. Furthermore, the CO_2 capture process increases complexity to the optimal design of desulphurization and other gas clean-up processes and deepens both energy consumption and the amount of coal necessary to generate the same amount of electricity (Stephens, 2005).

Table 3-3 - Overview of the advantages and disadvantages of pre-combustion technologies (EON, 2011) (Figueroa, et al. 2007)

Strengths	Weaknesses
Capturing CO_2 from the CO_2-H_2 mixture is, due to higher pressure and the partial pressure of the CO_2, easier than capturing it from the flue gas after combustion	Complex equipment with many individual processes
Most advanced capture technology	Unsuitable for retrofit onto, and only limited similarities with, existing conventional power plants; applicable mainly to new plants, as few gasification plants are currently in operation
Low overall emissions, low fresh-water consumption, and high CO_2 purity	Improved thermal efficiency only possible through greater plant complexity
H_2 can be used in other applications or stored	Highly complex systems limit operational flexibility

3.2 Power Plants and CCS

Since capturing CO_2 is still an emerging technology within the power sector, not yet demonstrated on a commercial scale, current performance and cost information related to CCS from power generation is limited to estimates from engineering studies and pilot projects (IEA, 2011b).

For coal-fired power generation, no single CO_2 capture technology appears to outperform available alternative capture processes in terms of performance and costs. For natural gas-fired power plants, post-combustion CO_2 capture is the option most predominantly considered across studies and appears to be the most attractive near-term option for NGCC (IEA, 2011b).

Compared to coal and natural gas-fired plants, information regarding biomass fired power generation with CO_2 capture is even scarcer (IEA, 2011b). However, solid biomass as a fuel is similar in many ways to coal, and the combustion technologies are, for that reason, similar (IEA, 2008). Thus, the CCS strategies that are being developed for coal could also be applied to biomass. In fact, biomass combination with CCS would outcome in a net removal of CO_2 from the atmosphere which may become an important option for a rapid reduction of CO_2 emissions (IEA, 2008).

3.2.1 Power Plants - CCS Tehcnologies Performance and Efficiency Penalties

The power plants perfomance with CO_2 capture technologies can be summarized in terms of plants efficiency, power output and CO_2 emissions.

Table 3-4 summarizes power generation performance data with and without CO_2 capture technologies (average OECD results). This data from the working paper “Cost and Performance of Carbon Dioxide Capture from Power Generation” from the IEA is based on estimates published over 5 years in major engineering studies from about 50 CO_2 capture installations at power plants.

Table 3-4 - Power generation performance (IEA, 2011b)

	Post-combustion capture from coal-fired power generation by amines	Post-combustion capture from natural gas-fired generation	Oxy-combustion from coal-fired power generation	Pre-combustion capture from IGCC
Net power output without capture (MW)	582	528	566	633
Net power output with capture (MW)	545	461	543	546
Net efficiency without capture, LHV (%)	41.4	56.6	41.6	41.4
Net efficiency with capture, LHV (%)	30.9	48.4	31.9	33.1
CO_2 emissions without capture (kg/MWh)	820	370	825	793
CO_2 emissions with capture (kg/MWh)	111	55	59	115
Relative decrease in net efficiency (%)	25	15	23	20

Depending on the fuel and technology used for combustion, the energy required to operate CO_2 capture technologies decreases the global efficiency of power generation and other processes. This leads to enlarged fuel supplies, enlarged quantities of waste and CO_2 emissions production per unit of electricity output.

Average net efficiency penalties for post-combustion and oxy-combustion capture are 10% points relative to a pulverised coal plant without capture, and 8% points for pre-combustion capture compared to an IGCC (IEA, 2011b).

For post-combustion CO_2 capture from NGCC performance projections include net efficiency penalties of 8% points (IEA, 2011b).

The reduction of energy requirements for CO_2 capture and efficiency improvements in the energy conversion processes are considered critical for upcoming technology development in order to reduce overall environmental impacts and costs.

3.2.2 Power Plants - Retrofitting with CCS technologies

CO_2 capture technologies can be applied in new power plants or they can be retrofitted to existing plants. Two possibilities for retrofitting CO_2 capture in an existing coal-fired power station are post-combustion CO_2 capture from the flue gas, e.g. by means of MEA scrubbing and converting the combustion process to use pure O_2 (oxy-fuel combustion) (RECCS, 2008).

Retrofitting entails some drawbacks since there may be site restrictions and limited land for capture equipment; a long remaining plant life may be required to vindicate the large expense of installing capture equipment; old plants often have low energy efficiencies and the installation of CO_2 capture technologies will have a proportionally larger impact on the net output than in high efficiency plants (IPCC, 2005).

In order to reduce the site constraints, new power plants could be projected “capture-ready”, that is, with sufficient space and facilities available for latter on simpler installation of CO_2 capture equipment. Retrofits require case-by-case careful design-based examination. For particular types of capture retrofit such as pre-combustion and oxyfuel combustion much of the required retrofit equipment could be installed in a separate site if needed (IPCC, 2005).

The other constraints could be largely reduced by upgrading or considerably rebuilding the existing plant when capture is retrofitted. In fact, old inefficient boilers and steam turbines could be substituted by modern, high efficiency supercritical boilers and turbines or IGCC plants. As the efficiencies of power generation equipment are improving, the efficiency of the retrofitted plant with CO_2 capture could be as high as that of the plant without capture (IPCC, 2005).

3.3 CCS Technologies Applications beyond the Power Sector

CO_2 emissions associated to industrial energy use are expected to further grow in the next decades. The CO_2 emitting processes within industry are varied and so are the alternatives to reduce emissions, at the present and in the future. However, for achieving deep CO_2 emission reductions, industry is considered to have fewer alternatives to CCS than the power sector (UNIDO, 2010). Indeed, in many industry sectors, CCS is the only technology, with the exception of EE improvements, that allows for significant cuts in CO_2 emissions (IEA, 2011j).

Even if the majority of the short-term and cost-effective potential for CCS lies within the industrial sources of CO_2, most of the studies on the potential application of CCS have focused on the power sector, in particular coal-fired power plants applications. However, if CCS is to fulfil its potential and make the maximum contribution to the required emission reductions, this unevenness must be addressed (UNIDO, 2010).

The deployment of CCS in industry entails several analogous challenges as those associated to the power sector. Unproven technology in some cases, increased energy use and the price of novel technology will inhibit many projects (UNIDO, 2010).

In their report to the Muskoka 2010 G8 Summit, the IEA and the Carbon Sequestration Leadership Forum in partnership with the Global CCS Institute have called for the identification of a larger number of projects in industrial sectors and assistance for the development of CCS in developing countries (UNIDO, 2010).

In industry, CCS is currently considered a valuable solution for CO_2 emission reduction within:

- Industries that vent high-purity CO_2 into the atmosphere. These sources of CO_2 are relatively cost-effective to capture and could therefore embody early opportunities for CCS to be demonstrated;
- CO_2 intensive industries where CO_2 emissions are inherent to industrial processes, where it is technical and economically more difficult to reduce these emissions than in other sectors and where CCS becomes one of the only options for large scale emissions reductions as it is for the cement and steel industries (UNIDO, 2010) (IEA, 2008).

Additionally, and even if the costs for CO_2 capture can diverge considerably with the size, type and location of the industrial processes, the costs will be lowest for processes or plants that operate at high load factors and processes that can use waste heat to supply the energy requirements of CO_2 capture systems (IPCC, 2005).

3.3.1 High-purity CO_2 Sources

There are several processes in industry and in fuel production that attain a high purity, high concentration CO_2 off-gas. These CO_2 off-gases can be readily dehydrated, compressed, transported and stored.

Even if the CO_2 emissions from these activities are relatively modest when compared to the emissions from other activities, these CO_2 streams offer significant potential for ‘early opportunity’ CCS demonstration projects since there is no need for the energy-intensive step of CO_2 separation which provides lower cost options for CCS.

These CO_2 high purity sources include:

- Natural gas processing;
- H_2 production (including for the production of ammonia and ammonia-based fertilisers);
- Synthetic fuel production (e.g. CtL[6] and GtL[7]); and

[6] CtL (coal-to-liquid) is a synthetic hydrocarbon liquid that is converted form coal.

- Several organic chemical production processes (e.g. ethylene oxide production) (UNIDO, 2010).

The streams of waste gas generated within all the above mentioned industrial processes reach concentrations of CO_2 within 30% to 100% (UNIDO, 2010).

Natural Gas Processing

Natural gas reservoirs, other than natural gas, often contain a mixture of acid gases including H_2S and CO_2. H_2S needs to be removed to trace levels from natural gas since it is extremely corrosive when mixed with water and toxic to biological organisms (CCC, 2010). The CO_2 content of raw natural gas lies between 2% and 70% by volume (UNIDO, 2010). The required level of CO_2 removal varies depending on delivery route and end use (CCC, 2010). In order to comply with pipeline specifications CO_2 has to be removed until its content is reduced to below 2% by volume for transportation, (IPCC, 2005). Characteristic specifications for liquefied natural gas (LNG) and GTL feedstock are less than 0.2% of CO_2 content by volume (UNIDO, 2010). The basic natural gas processing (NGP) configuration for removing CO_2 from natural gas is termed 'gas sweetening'. This process results in an off-gas containing between 96% and 99% of CO_2.

Hydrogen Production

Each year, about 45 to 50 Mt of H_2 are produced globally. The bulk of H_2 production is based on fossil fuel feedstocks and around half of the H_2 generated is used to produce ammonia (UNIDO, 2010).

The methods used for H_2 generation from fossil fuel or biomass feedstock include: steam reforming, auto-thermal reforming (ATR), partial oxidation (POX), and gasification. All these methods are based in solid fuel gasification or natural gas reforming technologies to produce a syngas. The water-gas shift reaction process converts the syngas into a mixture of H_2 and CO_2 in variable quantities. In the case of a H_2 purified stream production, the CO_2 must be removed, whereas for synthetic fuel production, the water-gas shift conversion and gas clean-up steps are controlled to optimise the H_2/CO ratio (UNIDO, 2010).

Ammonia Production

Ammonia is one of the most used inorganic chemicals in the world and almost all nitrogen fertilizers are derived from ammonia (IFA, 2011). Natural gas is, worldwide, the dominant feedstock for ammonia production although a substantial portion (27%) is coal-based (IFA, 2011). CO_2 is routinely captured from ammonia production plants and the CO_2 removed is frequently used for the production of urea and nitro-phosphates within the same integrated plant. In most ammonia plants, CO_2 is separated from H_2 at an early stage generally using solvent absorption (IEA, 2008).

Synthetic Fuel Production

Given the potential to diminish oil dependency, the gasification of carbon-containing feedstocks (coal, natural gas and biomass) followed by hydrocarbon synfuel production has been receiving ample attention for some decades now. A variety of synfuels have been proposed: methanol, DiMethyl Ether (DME), naphtha/gasoline and diesel. These fuels production processes energy efficiencies range from 40% to 70% and as a consequence, they emit large amounts of CO_2 which can be captured and stored (IEA, 2008).

Ethylene Oxide Production

A key use for ethylene oxide (EO) is as a chemical intemediate in industry (EPA, 2000). EO is produced by direct oxidation of etylene over a silver catalyst (UNIDO, 2010). A side reaction produces, amog others, CO_2 and water. This CO_2 can be partly re-used in the reactor feed, vented or used in commercial applications (IEA, 2011j).

[7] GtL (gas-to-liquid) refers to a synthetic diesel fuel which is converted from natural gas.

3.3.2 Cement Industry

Cement production is an energy and raw material intensive process that emits large quantities of CO_2. These emissions arise from three separate sources: fuel combustion, limestone calcination in the kiln (while in the kiln, limestone is broken down into CO_2 and lime) and indirectly through electricity use (Ellerman, et al. 2010) (EPA, 2011).

Several different studies within the IEA, the Cement Sustainability Initiative (CSI) and the European Cement Research Academy (ECRA) have focused on the cement industry emissions reductions potential (IEA, 2009). According to the IEA, the cement industry is expected to play a key role within the CO_2 mitigation targets and CCS technologies are viewed as the main solution to achieve deep emission cuts within this sector (IEA, 2008).

The cement industry is active in R&D for CO_2 capture and post-combustion CO_2 capture and oxy-fuel technologies are recognized as possible options for the sector. Nevertheless, before 2020, CCS technologies in the cement industry are not likely to be commercially available since, before then, further research and pilot tests are required to gain practical experience with these technologies (IEA, 2009) (IEA, 2011j).

3.3.3 Iron and Steel Production

The production of iron and steel is also an energy intensive activity that generates substantial process-related CO_2 emissions and CCS technologies are considered the main option to achieve deep emission cuts within the sector (EPA, 2011) (IEA, 2008).

In the iron and steel making, depending on the production process used, a number of CO_2 capture systems have the potential to be implemented. However, CCS faces many uncertainties regarding cost, efficiency and technology choice. Direct CO_2 emissions of iron and steel production are very site specific and depend on the iron and steel making procedure (IEA, 2011j).

3.3.4 Refineries

Refineries produce significant amounts of CO_2 emissions depending on processed crude, extent of processing, and quality and composition of the product mix. A unique characteristic of the refining industry is that it entails multiple CO_2 sources and hence different technologies for emissions mitigation may be required depending on the source. The greatest sources of CO_2 emissions stem from process heaters, utilities and FFC, and from H_2 manufacture. All three key capture methods, post-combustion from diluted flue gas streams, pre-combustion capture from syngases, and oxy-fuel combustion for concentrating CO_2 in flue gases, could be applicable (IEA, 2011j).

The role of CCS in the refining industry is unclear owing to comparably high costs of capture, thigh refining margins and multiple different CO_2 sources within a refining site (DNV, 2010)

3.3.5 Pulp and Paper Plants

The pulp and paper is an increasing global industry that emits considerable amounts of CO_2. Approximately 60% of CO_2 emissions in the pulp and paper industry are from biomass fuel combustion. Pulp and paper industry off-gases contain 13-14% of CO_2 and post-combustion capture of CO_2 from these diluted streams is expensive. Black liquor gasification can be applied for production of liquid fuels and allow for easier capture of CO_2 using pre-combustion technologies. (IEA, 2011j).

3.4 CO_2 Transportation and Storage

For CCS technologies to be an effective option for global climate change reduction, and for its high costs to be justified, significant quantities of the CO_2 captured must be stored for a long period. To integrate point source emissions with geological storage solutions, CO_2 needs to be transported. In theory, CO_2 can be transported via pipeline (on-and offshore), by ship or by tank wagons. However, most of the CO_2 transportation is achieved via pipeline since pipelines are generally the most cost-effective way to transport large volumes of CO_2. Additionally, the technologies involved in pipeline transportation are the same as those extensively used for transporting natural gas, oil and several other fluids worldwide (CCSA, 2011). Therefore, this is a relatively 'mature' option, and has been in operation for some decades and comprises most of the existing CO_2 transportation infrastructures around the world. In North America, with an excellent safety track record (IEA, 2008), there is a 5900 km pipeline structure transporting approximately 50Mtpa of CO_2 for EOR (GCI, 2011a).

Transporting CO_2 by ship may as well be a competitive choice for transporting large volumes over long distances. Supposing port access, shipping may be the only practical option if onshore pipeline structures and appropriate storage locations are not available, and for the reason that offshore pipelines are considerably more expensive.

An Integrated CO_2 "network" for CCS

For CCS to be extensively deployed, a broad transportation infrastructure is necessary, and CO_2 pipelines will be required to serve many users. In fact, much of the already existing CO_2 pipeline structure in the world implements an integrated network[8] approach (GCI, 2011a).

Even if a network approach comprises additional risks, higher initial investment levels, and interoperability issues, the economies of scale and other benefits compared to a standalone individual CCS project can offer economic benefits and are inducing the expansion of proposed CCS projects (GCI, 2011a). Therefore, and as CCS builds from demonstration to commercialization, CO_2 networks will require co-ordination on a regional, national and international level to optimise infrastructure development and to reduce costs.

CO_2 Storage

The different types of geological storage presently under consideration within the Global CCS Institute are summarily described in Table 3-5. Table also presents the status of large-scale projects.

Table 3-5 – Types of geological storage and current status (GCI, 2011a)

Storage type	Description/Status	Current large-scale projects
Depleted oil and gas reservoirs	Previous characterization and may have some existing infrastructure to support injection Containment established; potential storage capacity exists and is relatively well understood through decades of oil and gas industry experience; e.g. established mass/balance calculations that account for the quantity of hydrocarbons removed Oil and gas industry has significant experience with injecting fluids into these formations Existing wells have to be managed for leakage risk, with some uncertainty over long-term reliability Small portion of potential pore volume	8 in the planning stages

[8] An integrated CO_2 'network' for CCS is considered to be a system with shared or interconnected infrastructure for CO_2 transportation from many anthropogenic capture sources to one or more underground injection sites for storage. The "network" concept does not preclude the transportation of CO_2 through ship.

Storage type	Description/Status	Current large-scale projects
Enhanced oil or gas recovery with CO_2	Commercially viable, particularly with significant experience and existing networks established in North America for injecting CO_2 for EOR Beneficial use value of the CO_2 can help to recover some of the costs associated with large-scale CCS demonstration projects Estimates in Western Canada put the storage capacity of EOR in the order of only 450 million tonnes. Overall capacity for storage seems to be limited Much more limited potential for EOR in Europe Opportunities for integrating CO_2 storage and EOR are certainly a key driver for CCS demonstration projects in North America Opportunities for Enhanced Natural Gas Recovery with CO_2 are not as developed Need to understand met CO_2 storage	32, most are in North America (5 operational; 24 planned; 3 in construction)
Deep saline formations	Demonstrated Sleipner, and more recently Snøhvit associated with oil fields (in-Salah gas) and hence, have the presence of sealing rocks Relatively wide global distribution, estimated to have by far the greatest storage capacity compared to other types Injection and behaviour of CO_2 is much less understood due to more limited sub-surface experience compared to depleted or near-depleted hydrocarbon reservoirs or EOR projects Uncertainty over storage capacity and efficiency, pressure effects of injecting CO_2 into formations already saturated, and ensuring integrity of the cap rock seal Risks of impacts on, for example, hydrocarbon or groundwater resources (including the potential for brine to flow through cap rocks) Lower pH levels that could mobilise heavy metals (e.g. arsenic and lead) A larger range of large-scale storage projects in deep saline formations is needed	26 (3 operational; 22 planned; 1 in construction)
Unmineable coal seams	Not currently demonstrated, with little testing at the pilot stage. Coal has a natural affinity for CO_2 relative to methane that is naturally found on the surfaces of coal; when CO_2 is injected it is absorbed to the coal surface and releases the methane that can be captured for economic purposes Low injectivity of coal and the consequent need for many injection wells may restrict potential except where CO_2 is used to enhance production from an existing coal-bed methane project. Beneficial reuse application – net greenhouse benefit?	None (TBC)?
Basalt formations	Not currently demonstrated, with little testing at the pilot scale	1 (planned)

In 2005 the global CO_2 storage capacity has been estimated by the IPCC in its CCS Special Report. These estimations range from 1700-11000 Gt of CO_2 for a variety of storage types, with deep saline formation storage making up the vast majority. The IPCC stated that there was enough capacity at a global level to store a total of 145Gt of CO_2 from emissions by 2050 (GCI, 2011a).

3.5 CCS Technologies - International Status

The following section intends to provide a snapshot of the current state of play within CCS projects developments, technology costs and legal and regulatory issues.

3.5.1 Projects

During 2010 important CCS project activity has been recorded. Several newly identified projects counterbalanced delays and cancellations. By the end of last year, 234 active or planned CCS projects were identified across a range of technologies, project types and sectors. Seventy-seven of these 234 projects are large-scale integrated projects (LSIP) (GCI, 2011a).

The asset lifecycle model represents the various stages in the development of a project (Table 3-6).

Table 3-6 – Asset lifecycle model (GCI, 2011a)

<table>
<tr><td colspan="5"></td><td rowspan="5">Final Investment Decision</td><td colspan="3"></td></tr>
<tr><td></td><td colspan="4">Planning</td><td colspan="3">Active</td></tr>
<tr><td>Project phase</td><td>Identify</td><td>Evaluate</td><td rowspan="2"></td><td>Define</td><td>Execute</td><td rowspan="2"></td><td>Operate</td></tr>
<tr><td>Developer’s goals</td><td>Establish preliminary scope and business strategy</td><td>Establish development options and execution strategy</td><td>Finalise scope and execution plan</td><td>Detailed design and construction</td><td>Operate maintain and improve costs</td></tr>
<tr><td colspan="3"></td><td>Select concept</td><td></td><td></td><td>Start-up</td><td></td></tr>
</table>

Of the 77 LSIP, 8 are operating projects and 4 projects are in the execution stage of the asset lifecycle. The remaining 65 LSIP are in different phases of development planning (phases of the asset lifecycle preceding the final investment decision) (GCI, 2011a).

All 8 operating LSIP and the 4 in execution are associated with the oil and gas sector: they either capture CO_2 via natural gas processing or they inject CO_2 for EOR (Table 3-7).

Table 3-7 – Active CCS LSIP (GCI, 2011a).

	Name	Location	Capture	Storage
Operation stage	Sleipner CO_2 Injection	Norway	Gas processing	Deep saline formation
	Snøhvit CO_2 Injection	Norway	Gas processing	Deep saline formation
	In Salah CO_2 Injection	Northhern Africa	Gas processing	Deep saline formation
	Weyburn-Midale CO_2 Monitoring and Storage Project	Canada/United States	Pre-combustion (synfuels)	EOR with MMV
	Rangely Weber Sand Unit CO_2 Injection Project	United States	Gas processing	EOR with MMV
	Salt Creek Enhanced Oil Recovery	United States	Gas processing	EOR
	Enid Fertiliser	United States	Pre-combustion (fertiliser)	EOR
	Sharon Ridge EOR	United States	Gas processing	EOR
Execution stage	Southern Company IGCC Project	United States	Pre-combustion (power)	EOR
	Occidental Gas Processig Plant	United States	Gas processing	EOR
	Enhance Energy EOR Project	Canada	Pre-combustion (fertiliser and oil refining)	EOR
	Gorgon Carbon Dioxide Injection Project	Australia	Gas processing	Deep saline formation

Within the power generation sector there are 42 LSIP in development planning. Most of those are planned for coal-fired applications and are in different stages of development planning. An important exception is the Southern Company IGCC Project, which is in the Execute phase (GCI, 2011a).

Among the LSIP there are 2 iron and steel projects, 1 cement project and 1 pulp and paper project (GCI, 2011a).

Most LSIP are found in developed countries, such as in the United States, Europe, Canada and Australia, with a few in emerging markets such as China. Driven by a variety of incentives being offered by the government as well as the extensive practice of EOR, the United States has the largest amount of newly identified LSIP and dominates project activity. The biggest sum of cancellations and delays of LSIP has occurred in Europe. Still, Europe has also had the highest amount of projects moving forward in the asset lifecycle. With six and five LSIP, the United Kingdom and the Netherlands present the largest number of projects in the Europe. Even though public funding (from the European Union and some National Governments) is supporting activity, weak economic conditions and difficulties surrounding use of onshore storage sites have increased uncertainty in investment decision making in Europe (GCI, 2011a).

Figure 3-1 presents all active and planned projects by industry sector and by asset lifecycle stage.

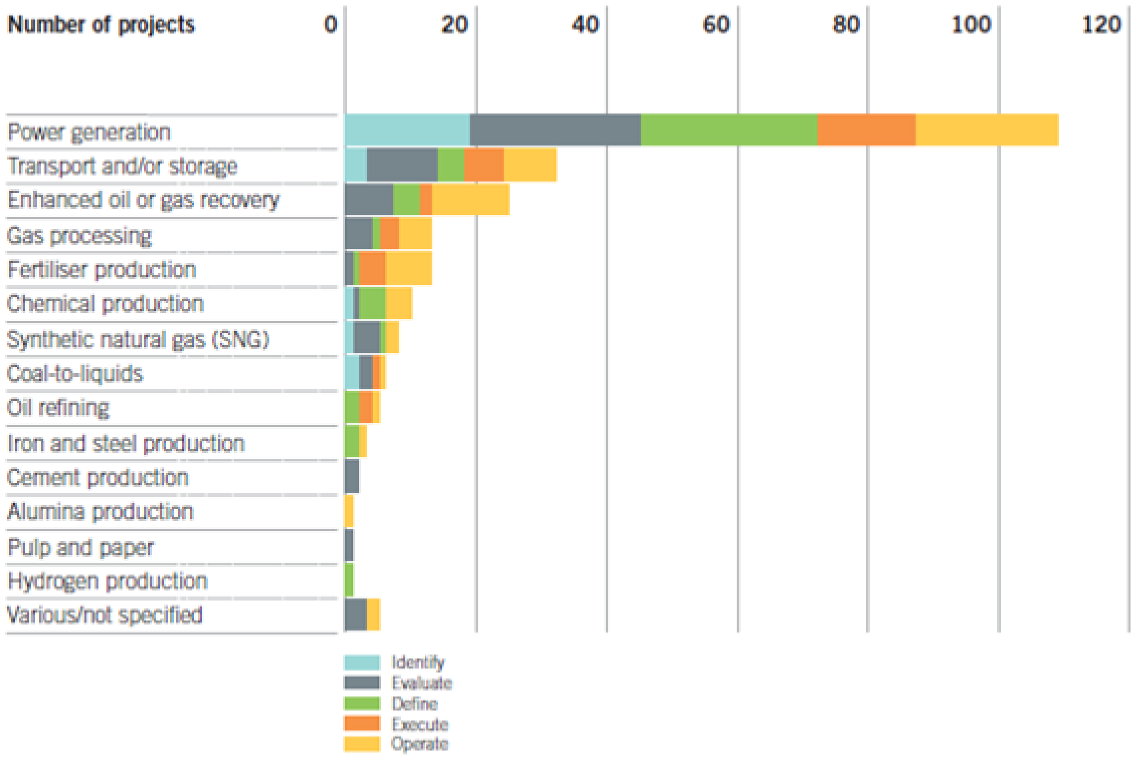

Figure 3-1 - All active and planned projects by industry sector and by asset lifecycle stage (GCI, 2011a).

The power industry, which has been, up till now, the foremost beneficiary of government arrangements in support of large-scale demonstration of CCS, accounted for almost half of all active and planned project activity in 2010 (GCI, 2011a).

Pre-combustion and post-combustion capture technologies dominate the LSIP, with 33 projects (43%) and 21 projects (27%) correspondingly (GCI, 2011a).

The flexibility of the pre-combustion capture technology is shown through the spread of projects across power generation (19), synthetic natural gas (5), coal-to-liquids (3), fertiliser production (3), oil refining (2) and H_2 production (1). The bulk of pre-combustion capture within LSIP is being developed for new build facilities. In contrast, around 60% of the post-combustion capture projects involve retrofitting existing facilities (GCI, 2011a).

Oxy-fuel combustion is being planned or considered within 4 projects, all in the power generation industry, including the recently restructured FutureGen 2.0 project in the United States (GCI, 2011a).

In order to compare the status of technologies being considered for CCS implementation there are 4 categories to designate the level of technology maturity in use: commercial, demonstration, pilot and bench. These are primarily defined by the scale of the activity in a particular industry. For instance a commercial process is presented for sale by one or more trustworthy vendors with standard commercial assurances; a large-scale demonstration process entails the integration of technologies into a full-size structure to demonstrate viability and commercial readiness in a specific application. When in a pilot stage, a process or technology is being tested in a realistic environment, typically at one to two orders of magnitude minor than a full-scale demonstration, once it has been created in a controlled environment in a bench or laboratory scale successfully (GCI, 2011a).

All active and planned projects by industry sector and by technology maturity are presented in Figure 3-2.

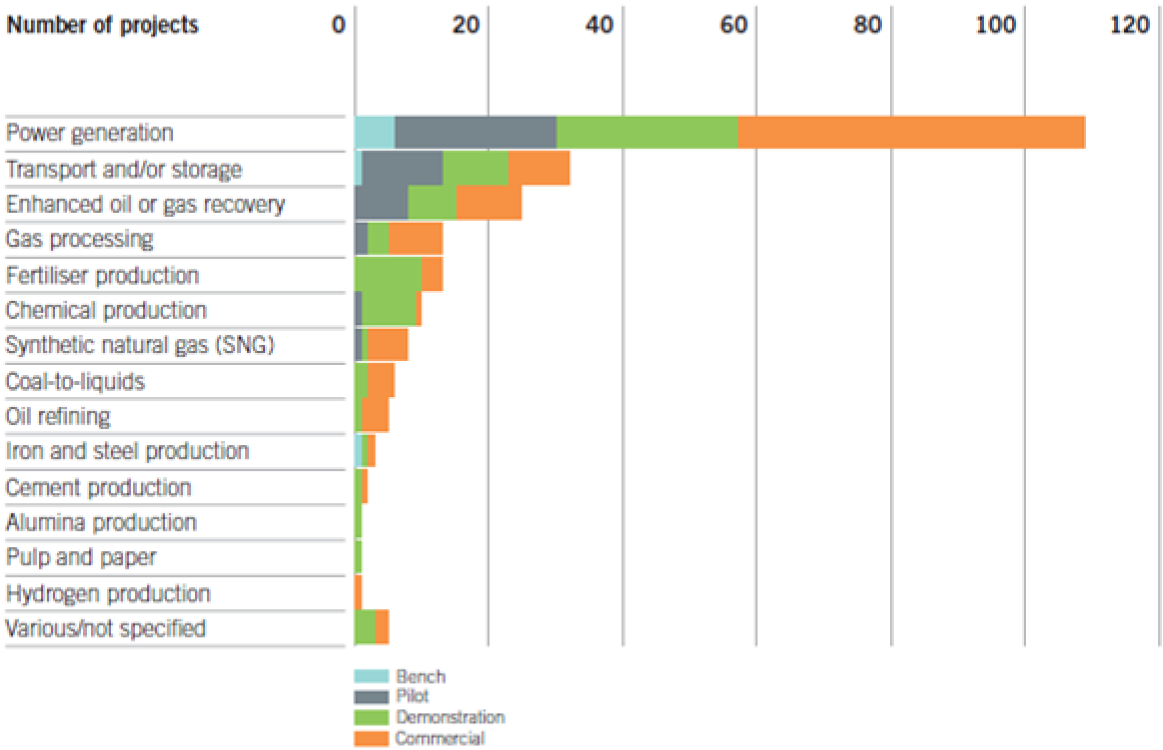

Figure 3-2 - All active and planned projects by industry sector and by technology maturity (GCI, 2011a).

Pipelines are the most common means for CO_2 transport within LSIPs and almost 90% of LSIPs involve transporting CO_2 or are planning to transport CO_2 via pipelines (GCI, 2011a).

Potential storage of CO_2 is evenly split between EOR and deep saline formations options (GCI, 2011a). Table 3-8 presents the CO_2 storage current large-scale projects but does not include those projects where the exact storage type has not been specified.

Table 3-8 – CO_2 storage large-scale projects (GCI, 2011a)

Storage type	Current large-scale projects
Depleted oil and gas reservoirs	8 in the planning stages
Enhanced oil or gas recovery with CO_2	32, most are in North America (5 operational; 24 planned; 3 in construction)
Deep saline formations	26 (3 operational; 22 planned; 1 in construction)
Unmineable coal seams	None (TBC)
Basalt formations	1 (planned)

In the near to medium term EOR will probably continue to be a common form of potential storage. Despite the fact that this route can act as an ‘enabler’ for a less costly and faster mechanism for the demonstration of capture technologies, additional improvements in the monitoring and verification of injected CO_2 to demonstrate permanent storage is considered crucial. Deep saline formations offer much greater storage potential in the longer term but, the time and expense of proving up this storage option, particularly in offshore applications, should not be undervalued (GCI, 2011a).

Several LSIPs in the Define phase have satisfactory funding to complete their current asset lifecycle stage of development; however, a large number of projects in the Identify and Evaluate stages may not advance except if additional funding is forthcoming (GCI, 2011a).

3.5.2 Costs

Developing and deploying CCS LSIP is challenging and one of the main obstacles is the relatively high cost of the technologies to capture the CO_2, transport it and safely store it compared to the same facilities without CCS.

Project costs can fluctuate significantly and published estimates show an extensive range of costs for CCS owing to the diversity of project-specific factors. These factors, among others, include: the scale of the facility, its expected life-time, load factor and labour rates; the type and costs of fuel consumed; the selection of CCS technology and design; the CO_2 capture targets; the distances, terrains and the CO_2 quantities involved to transport and storage (IPCC, 2005).

Investment decisions on CCS projects depend on several case-specific boundary circumstances such as, among others: the emission market; the national or regional policy and regulatory frameworks; the availability of incentive and financing structures; they also depend on the experience and risk profile of the investor (IEA, 2011b).

Each part of the CCS value chain includes multiple variants and publicly available CCS technologies cost data are scarce; therefore, without access to detailed project specific information, project based costs provide limited guidance on underlying technology costs.

However, one thing is certain: within the whole CCS process chain the CO_2 capture technologies are generally expected to entail, by far, the largest absolute cost.

In the power sector, and as previously stated, CO_2 capture is still an emerging technology that has not been demonstrated on a commercial scale and related cost information is still *uncertain* and is based on feasibility studies and pilot projects. The accuracy of techno-economic data for CCS is expected to improve when supplementary information from the first commercial scale demonstration plants are available (IEA, 2011b).

Table 3-9 presents economic data for CO_2 capture within power generation, including CO_2 conditioning and compression. It presents average OECD results, since available data for CO_2 capture from power generation in non-OECD countries is very limited. This data from the working paper “Cost and Performance of Carbon Dioxide Capture from Power Generation” from the IEA is based on estimates published over 5 years in major engineering studies from about 50 CO_2 capture installations at power plants. Capital costs and levelised cost of electricity (LCOE[9]) are re-evaluated and updated to 2010 cost levels to allow for a consistent comparison.

Table 3-9 – Economic data for CO_2 capture (including conditioning and compression) in power plants (2010 USD) (IEA, 2011b).

	Post-combustion capture from coal-fired power generation by amines	Post-combustion capture from natural gas-fired generation	Oxy-combustion from coal-fired power generation	Pre-combustion capture from IGCC
Capital cost without capture (USD/KW)	1899	925	1931	2356
Capital cost with capture (USD/KW)	3135	1541	3153	3166

[9] LCOE is commonly used as a measure of comparing generating costs of different power generation and capture technologies over a plant’s economic life. LCOE is equal to the present value of the sum of discounted costs divided by the total electricity production.

	Post-combustion capture from coal-fired power generation by amines	Post-combustion capture from natural gas-fired generation	Oxy-combustion from coal-fired power generation	Pre-combustion capture from IGCC
Overnigh cost[10] without capture (USD/KW)	2162	960	2263	2586
Overnigh cost with caputre (USD/KW)	3808	1715	3959	3714
LCOE without capture (USD/MWh)	66	77	62	75
LCOE with capture (USD/MWh)	107	102	102	104
Cost of CO_2 avoided (USD/tCO_2)	58	80	52	43
Relative increase in overnight cost	75%	82%	74%	44%
Relative increase in LCOE	63%	33%	64%	39%

It is expected that the cost of CCS technologies will decline in the future in parallel with technical and scientific progress.

CO_2 capture applications for industrial processes have not been, as previously reported, investigated to the same degree as those from power generation. WorleyParsons estimated costs of CCS applications to existing industrial systems for: blast furnace production of steel; cement kiln/furnaces; natural gas processing; and fertiliser production (ammonia). As formerly discussed the latter two processes attain a high purity, high concentration CO_2 off-gas and therefore do not require the energy-intensive step of CO_2 separation which results on lower cost routes for CCS technologies deployment.

Table 3-10 – CCS costs in industrial processes (GCI, 2011a).

	Blast furnace steel production	Cement	Natural gas processing	Fertiliser production
Avoided CO_2 cost (US$/tonne CO_2)	54	54	19	20

Compared to CO_2 capture processes data, transportation and storage associated data are even more difficult to generalise, since that they are extremely site-specific or even unique for every project (IEA, 2011b).

Costs for CO_2 transportation depend on distance and quantities involved and on local geographical conditions. Still, the transport costs are generally considered low when compared to the CO_2 capture costs. As stated before, the transportation of CO_2 by pipeline offers potential cost savings through combining the flow of CO_2 from multiple sources into a single pipeline to a common storage site (GCI, 2011b).

A balanced decision on transport modes and a rigorous matching of CO_2 sources and sinks over time are evident opportunities to reduce costs.

The costs of CO_2 storage are site specific, driven by the geology of the storage formation (GCI, 2011b). Recently released economic studies suggest that storage costs contribute to less than 5% under ideal conditions, rising to about 10% for storage sites with 'poorer' geologic properties. In some cases, without a suitable storage site that is reachable by effective transport units, CCS may not be an option

[10] Overnight costs include, according to OECD terminology: pre-construction or owner's costs, engineering and construction costs and contingency costs.

3.5.3 Legal and Regulatory Framework

In order to boost CCS deployment, important progress is being made in the development of CCS legal and regulatory frameworks worldwide (IEA, 2011c). In fact, in recent years the international community has amended several international legal instruments, including international marine legislation and climate change frameworks. However, a number of important issues remain unresolved and legal and regulatory progress has been largely circumscribed to OECD countries and regions with less progress realized in non-OECD regions (GCI, 2011a). In the latter countries, CCS regulatory development will be of particular importance, especially in the largest emitting countries such as China.

To allow for offshore CO_2 storage, the 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Protocol) was amended, in November 2006. This amendment came into force without having to be ratified by contracting parties since the amendment was made to the Annex of the Protocol (GCI, 2011a).

In October 2009 the London Protocol was once again amended to allow cross-border transportation of CO_2 intended for storage, however, this amendment modifies the body of the protocol and therefore it will only enter into force once two-thirds of all contracting parties to the London Protocol have accepted the amendment. Thus, under the London Protocol, CO_2 cross-border transportation is still prohibited (GCI, 2011a).

In 2007, to embrace analogous alterations, the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention) was amended as well. Yet again, the amendments are not in force and necessitate ratification by seven contracting parties under the OSPAR Convention’s ratification provisions to enter into effect. So far, six contracting parties to the OSPAR Convention have ratified the amendment, which means that the amendment may enter into force imminently, with only another party required to ratify the modifications (GCI, 2011a).

Additionally, important advancement has been accomplished in addressing some of the most challenging CCS legal and regulatory issues such as long-term liability, with several countries and regions having launched regulatory approaches to address this subject (GCI, 2011a).

At the COP16 Climate Change negotiations in Cancun, in November and December 2010, within the international frameworks for climate change, it has been established that CCS ought to be entitled as a CDM[11] project activity, once different specific issues are addressed and resolved in an appropriate way. This mechanism embodies the most significant step towards an international encouragement for regulating and supporting CCS projects in developing countries within the past five years (GCI, 2011a).

In Europe the development of CCS legal and regulatory frameworks is founded around the European Union CCS Directive (Directive 2009/31/EC). This Directive establishes a framework for regulating CO_2 storage, including requirements on permitting, composition of the CO_2 stream, monitoring, reporting, inspections, corrective measures, closure and post-closure obligations, transfer of responsibility to the state, and financial security. This Directive also amends several other European Union laws to establish requirements on capture and transport operations and diminish existing legal obstacles to the CO_2 geological storage (GCI, 2011a).

[11] The Clean Development Mechanism (CDM) of the Kyoto Protocol allows projects in developing countries to generate emission credits if they result in emission levels lower than would otherwise be the case; these credits can be marketed and eventually counted against a developed country's emission obligation.

4 COMET Project

The COMET (Integrated infrastructure for CO_2 transport and storage in the west MEdiTerranean) project, funded under 7th FWP (Seventh Framework Programme[12]), aims to study the techno-economic feasibility of integrating CO_2 transport and storage infrastructures in the West Mediterranean region, within Portugal, Spain and Morocco.

The project feasibility study will take into account several scenarios of energy system development for the time period 2010-2050, the location and development of the major CO_2 point sources and the available potential for geological storage in each of those countries. The long-term development of the Portuguese, Spanish and Moroccan energy systems is modeled and evaluated via the technical economic models MARKAL/TIMES. MARKAL is the acronym for MARket Allocation and TIMES – which is the next generation version of MARKAL – stands for the Integrated MARKAL-EFOM System. TIMES is an economic model generator for local, national or multi-regional energy systems, which provides a technology-rich basis for estimating energy dynamics over a long-term, multi-period time horizon. It is usually applied to the analysis of the entire energy sector, but it may also be applied to study in detail single sectors such as, for example, the electricity and district heat sector.

The need for a joint CCS infrastructure in the West Mediterranean is related to the geographical proximity, to the increasing connections between the energy and industrial sectors in the area, to the continuity of sedimentary basins that can act as possible storage reservoirs and to the existing experience in managing a large gas transport infrastructure, such as the natural gas pipeline coming through Morocco, to Spain and Portugal. The consortium is coordinated by INETI (Portugal), and comprises 7 research institutions, 4 Universities, 1 SME and 5 energy companies from 6 European countries and Morocco.

It is expected that the project results will generate insights that can contribute considerably to the deployment of CCS in the area.

The COMET project is divided within the following 7 Work Packages (WP):

WP1: Project management and coordination

WP2: Identification of the location and the amounts of CO_2 emissions from the sources (Portugal, Spain and Morocco).

WP3: Identification of the locations and the storage capacity of potential sinks in the region (Portugal,

WP4: GIS[13] integration of all the information and elements of a CO_2 transmission network

WP5: Analysis of the Moroccan, Portuguese and Spanish energy systems and its modelling via MARKAL/TIMES.

WP6: In depth assessment of the most promising infrastructure options (scenario building, transport costs, technical-economic evaluation of different options).

WP7: Promotion, Dissemination and International collaboration.

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[12] FP7 is the short name for the Seventh Framework Programme for Research and Technological Development. This is the EU's main instrument for funding research in Europe and it will run from 2007-2013. FP7 is also designed to respond to Europe's employment needs, competitiveness and quality of life.

[13] A geographic information system (GIS) integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information.

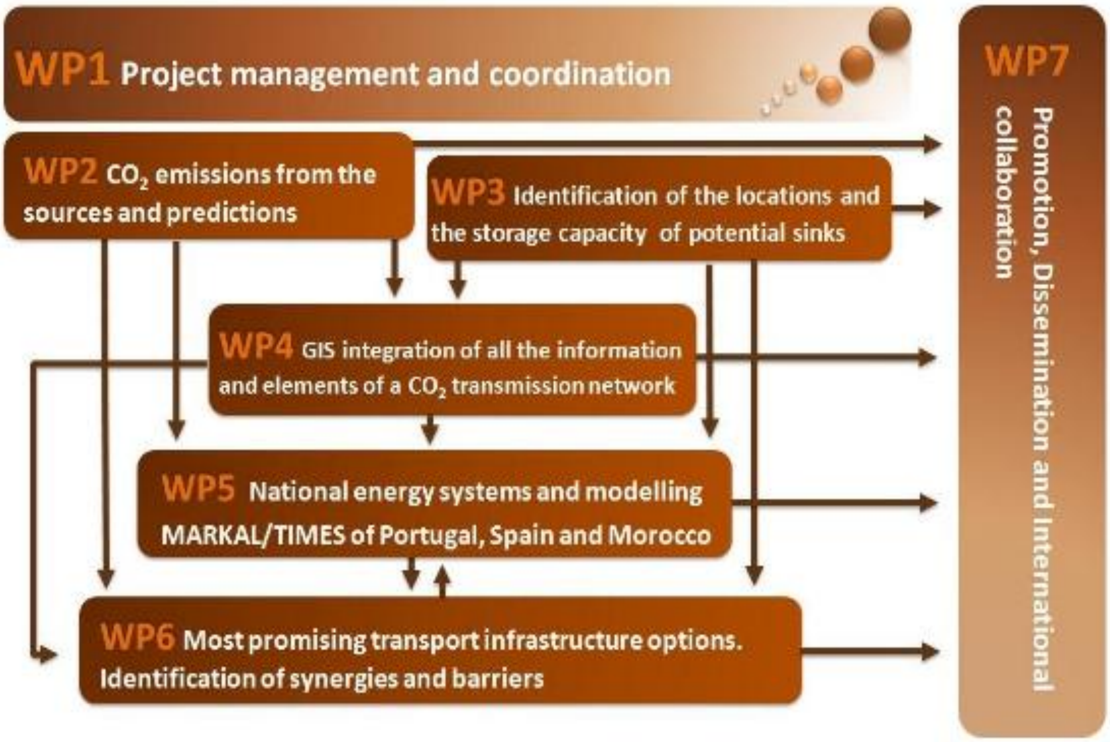


Figure 4-1- COMET project structure (COMET project, 2011)

As part of the WP5 of the COMET project, this thesis's gathers and discusses the quantitative and qualitative information to, for the first time, model the energy system of Morocco via MARKAL/TIMES and includes an analyses of the primary modelling outcomes.

Some work already existed related to the evolution of the energy sectors in Portugal and Spain, with MARKAL/TIMES models having been developed individually for the two countries. The COMET project will integrate those models, together with the model developed from scratch for Morocco, while updating the three models.

The input information to model the energy system of Morocco includes, among others: energy transformation, consumption and emissions trends data of the energy sector and other industrial activities; the identification of the installed capacity and future perspectives; an assessment of the energy end-use sectors; an estimation of the national energy related resources; and an assessment of relevant energy related policies as MARKAL/TIMES is well suited to evaluate the global impact of policies within the energy sector. The information collected is based on several sources, either national or international and for modelling purposes most of it refers to 2005 and 2008.

5 Moroccan Energy System

5.1 General Description of the Country

Morocco is geographically positioned in the northwest corner of the African continent, between the North Atlantic Ocean (to the west) and the Mediterranean Sea (to the northeast) (Figure 5-1). The country shares borders with Algeria in the east and with Mauritania in the south. This Maghreb country is separated from Europe by the Strait of Gibraltar and is sited at approximately 14 km from Spain at the nearest point. Rabat is the capital city.

Figure 5-1 - Moroccan territory (GPM, 2011)

With an area of 710850 km^2 and a large extension in latitude, from 21° to 36° north, this country comprises four topographical zones: the Atlas and Rif mountain ranges to the north reaching altitudes of 4165 m; the Sahara desert to the south; the fertile coastal plains to the west and the drier Anti-Atlas region in the centre.

The country coast extends over 3500 km a fact that has an important effect on the climate, commercial relations, tourism, fishing activities, and in coastline urbanization. The dominating weather in Morocco is Mediterranean, temperated in the west and in the north by the North Atlantic Ocean. Inside the country, the weather is more continental with major differences of temperature. Rain fall is concentrated in the winter months in line with northern hemisphere weather patterns. The hot and dry summer months have temperatures as high as 40°C throughout the country and even superior in some remote inland regions. The Atlas area is very humid, and snowfalls are frequent during the winter months. The south has desert weather. Morocco is part of the subtropical zone and it is exposed in the summer to the conditions of the warm dry zone and to the fresh, wet and moderate conditions in the winter. There are numerous rivers in the country. The main ones are the Moulouya River, which drains into the Mediterranean Sea, and the Sebou and Oum Rbiâ Rivers, which flow into the Atlantic Ocean.

Ready to be approved by the parliament is the division of the country within the following 12 regions: Eastern region and Rif, Tanger-Tétouan, Fès-Meknès, Rabat-Salé-Kénitra, Beni Mellal-Khénifra, Casablanca-Settat, Marrakech-Safi, Drâa-Tafilalet, Souss-Massa, Guelmim-Oued noun, Laâyoune-Saquia al hamara, Ed dakhla and Oued eddahab.

5.2 Macro and Socio-Economic Drivers

5.2.1 Population

In 2004 the Moroccan population reached 29891708 inhabitants and according to the General Census carried out that year by the High Planning Commission, the urban population amounted to 16463634 while the rural population amounted to 13428074 (PNM, 2006). In 2004 the urbanization level reached 55.1% increasing from 51.4% in 1994. In 1994 the average number of people per household was 5.9 (6.6 in rural areas and 5.2 in urban areas) and in 2009 the average number of people decreased to 4.9 per household (5.8 in rural areas and 4.5 in urban areas) (HCP, 2009).

In 2010 the population reached 31.851 million and there were 40 inhabitants per km^2. Table 5-1 presents two national population projections (from Eurostat and from the Second National Communication to the UN Framework Convention on Climate Change).

Table 5-1 - Moroccan population indicators (Eurostat, 2010; Eurostat 2011 ; SNC, 2010)

	Population as of 1 January (1000)			Projections (1000)		
Year	2003	2008	2010	2020	2030	2050
Population (Eurostat)	29.353	31.009	31.851	36.200	39.259	42.583
Population (Second National Communication to the UNFCCC)	n.a.	n.a.	n.a.	35.112	37.994	n.a.

Note: n.a. = not available

5.2.2 Economy

Over the last two decades, Morocco has effectively implemented audacious programs for economic and social development. Moroccan leaders introduced solid reforms to liberalize trade relations with the E.U. and U.S., deeply invested in basic infrastructure, steadied macroeconomic policy, expanded investment opportunities, ameliorated education, and opened the political system (UNCTAD, 2011). Table 5-2 presents the last decade GDP per capita development.

Table 5-2 - GDP per capita at 2010 market prices (EUR) (Eurostat, 2010)

Year	GDP per capita
2000	1412
2002	1452
2004	1536
2006	1714
2007	1779

The Moroccan economy has been consistently reliant on the agricultural sector but over the past decade it has embarked upon a diversification of its structure. Progressively, more growth comes from the secondary and tertiary sectors (AEO, 2011). The GVA by sector within 2000 and 2006 is presented in Table 5-3.

Table 5-3- GVA by sector (%) (Eurostat, 2009)

Year	Agriculture	Industry	Construction	Services
2000	14.9	24.0	5.1	56.0
2001	16.5	22.0	5.5	55.9
2002	16.5	21.8	5.5	56.2
2003	17.3	22.2	5.7	54.8
2004	16.4	21.4	6.4	55.8
2005	13.3	22.5	6.5	57.6
2006	15.7	21.6	6.2	56.5

Figure 5-2 presents the GDP by sector in 2007.

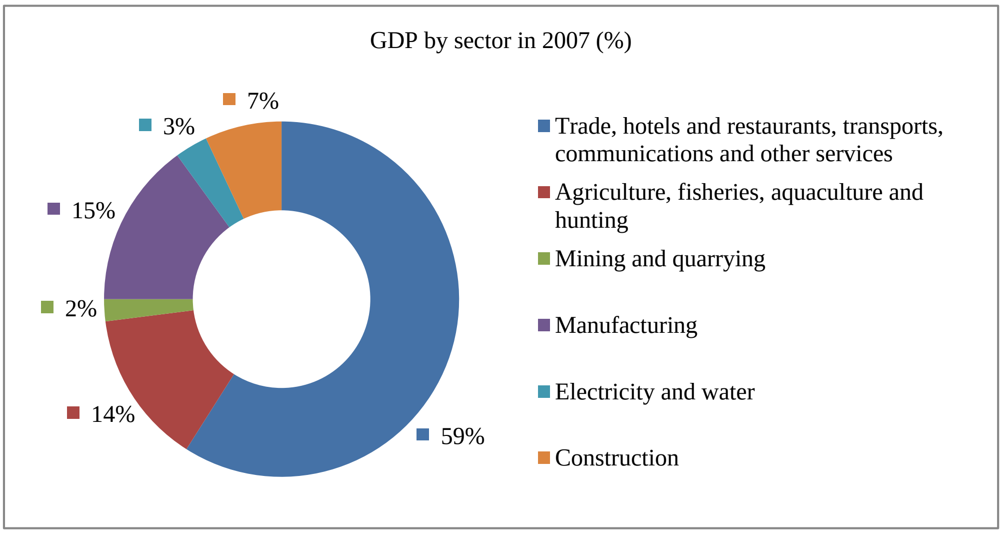


Figure 5-2- GDP by sector in 2007 (percentage) (AEO, 2009)

Even if the global economic crisis in 2008 highlighted some structural weaknesses, in particular, within some export-oriented sectors such as textiles and clothing, the GDP kept on growing.

Table 5-4 presents the Moroccan GDP annual growth at constant prices, the GDP deflator evolution and the GDP based on purchasing-power-parity (PPP) share of world total development until 2016 (IMF projections).

Table 5-4 - Moroccan GDP annual growth, GDP deflator evolution and the GDP based on purchasing-power-parity (PPP) share of world total development until 2016 (IMF, 2011)

Year	GDP annual growth at constant prices (% change)	GDP deflator (Index)	GDP based on purchasing-power-parity (PPP) share of world total (%)
2004	4.802	103.902	0.194
2005	2.979	105.425	0.191
2006	7.760	107.041	0.195
2007	2.706	111.245	0.191
2008	5.587	117.769	0.196
2009	4.949	119.932	0.207
2010	3.150	121.123	0.206
2011	3.856	124.636	0.206

Year	GDP annual growth at constant prices (% change)	GDP deflator (Index)	GDP based on purchasing-power-parity (PPP) share of world total (%)
2012	4.583	128.250	0.207
2013	4.941	131.970	0.208
2014	4.949	135.795	0.209
2015	5.495	139.735	0.210
2016	4.996	143.787	0.210

Note: From 2010 until 2016 the cells indicate IMF staff estimates

5.3 Overview of the Energy System

Morocco is an emerging country, in full economic and social development. Therefore, and with an increasing population, in order to sustain this development, the primary energy consumption has risen. During the last decade (2000-2010), the energy consumption has increased by 5% per year on average mainly stimulated, during the last five years, by a higher electricity consumption which has increased by 7.5% per year on average (UNCCC, 2010). This power consumption upsurge is attributable to both the expansion of the rural electrification as part of the Global Rural Electrification Program (PERG), a project launched by the Moroccan authorities and the ONE (National Office of Electricity) in 1996, and to the country's economic progress. According to the Minister of Energy, Mines, Water and Environment in 2020, primary energy and electricity consumption will double, compared to their level in 2008, and by 2030 these consumptions will be three and four times greater, respectively (UNCCC, 2010).

In 1995 the energy use was of 8592 ktoe whereas by 2008 it reached 14977 ktoe (Figure 5-3). Energy use (kt of oil equivalent) refers to use of primary energy before transformation to other end-use fuels, which is equal to indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport (World Bank, 2011).

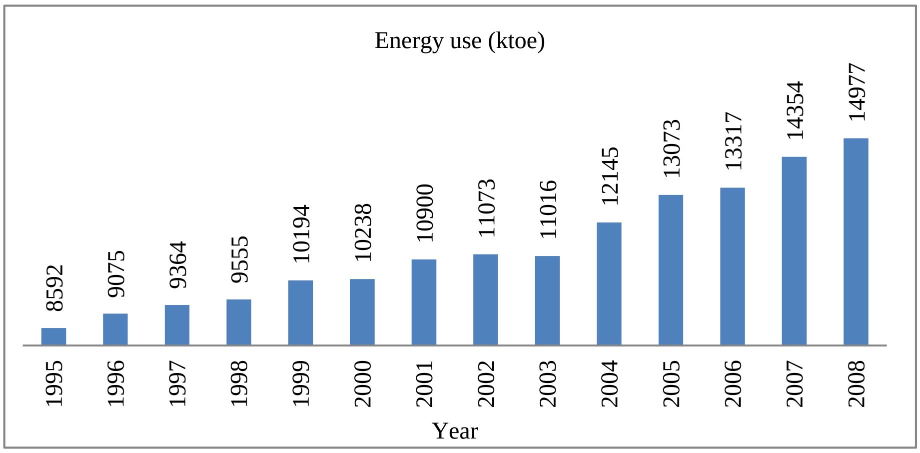


Figure 5-3 – Energy use evolution between 1995 and 2008 (kt of oil equivalent) (World Bank, 2011)

The variation of energy use per capita (kg of oil equivalent) within 1995 and 2008 is illustrated in Figure 5-4.

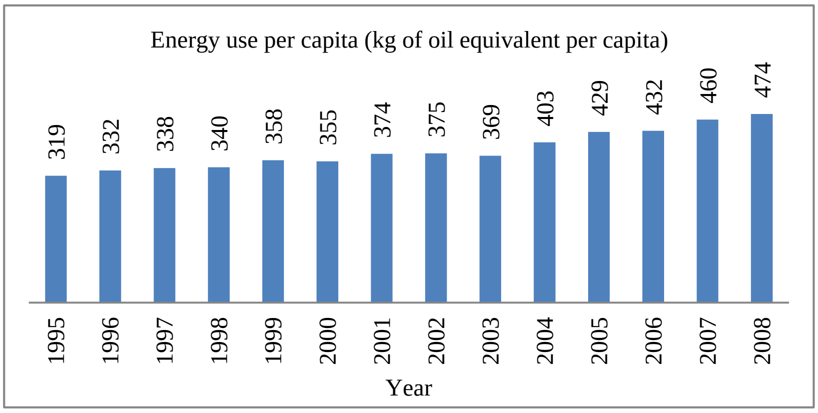


Figure 5-4 - Energy use per capita (kg of oil equivalent per capita) (World Bank, 2011)

Figure 5-5 presents the rising of the TPES by type of fuel within 1972 and 2008 (it excludes electricity trades).

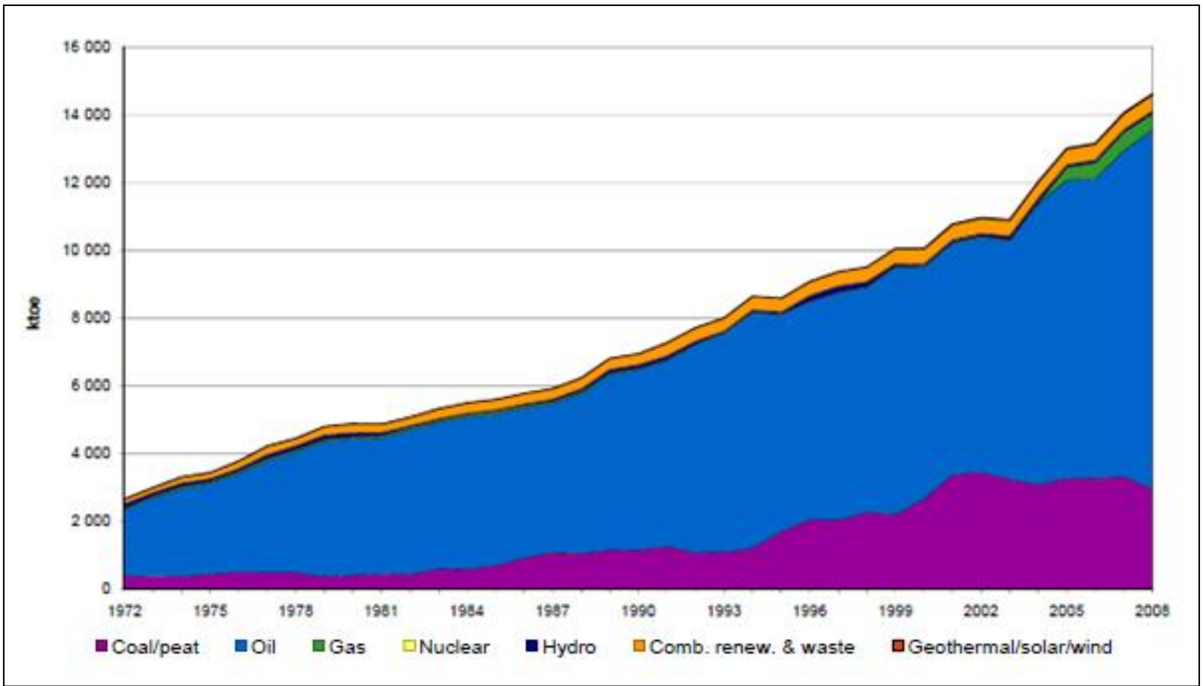


Figure 5-5 - Total primary energy supply excluding electricity trade (IEA, 2011i)

As illustrated in Fig 5-5 the Moroccan energy supply is heavily based on fossil fuels, mainly on oil and on a smaller scale, on coal/peat products. In 2005 gas was first introduced in the primary energy supply mix. It is expected that fossil fuels remain dominant for at least the next three decades in the Moroccan energy supply (UNCCC, 2010).

Figure 5-6 presents the fossil fuel (coal, oil, petroleum, and natural gas products) energy consumption as percentage of total between 1995 and 2008.

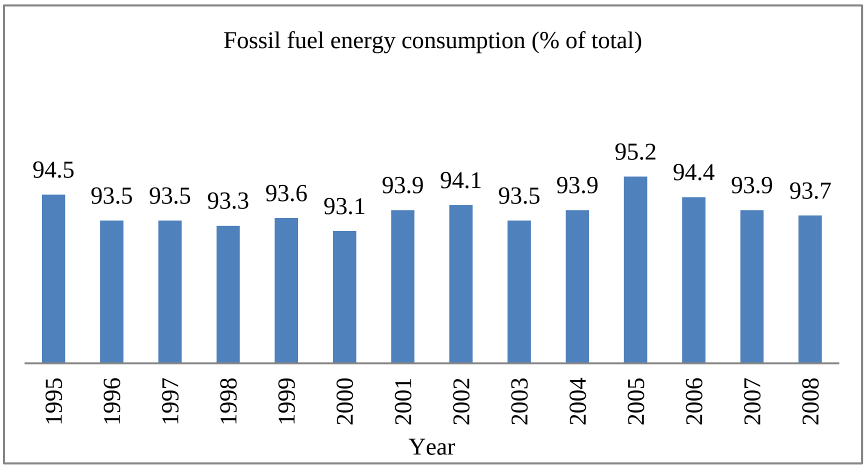


Figure 5-6 – Fossil fuel energy consumption (% of total) between 1995 and 2008 (World Bank, 2011)

Figure 5-7 presents the combustible renewables and waste consumption as percentage of the total energy consumption. Combustible renewables and waste comprise solid biomass, liquid biomass, biogas, industrial waste and municipal waste, measured as a percentage of total energy use.

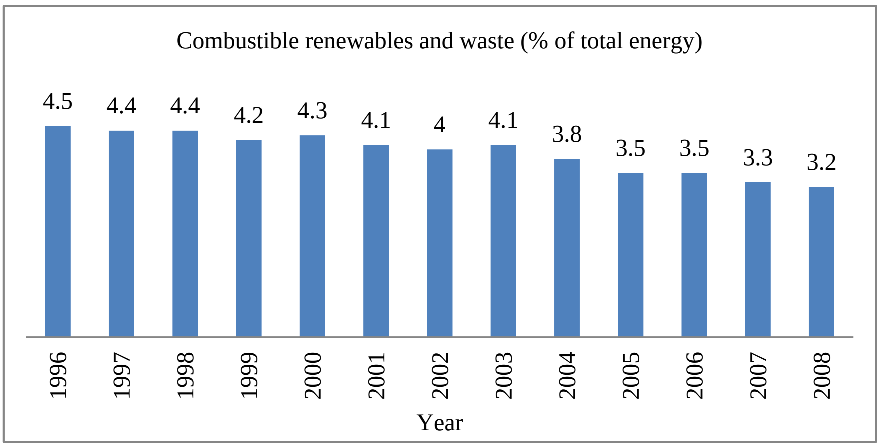


Figure 5-7 – Combustible renewables and waste consumption (% of total energy) between 1996 and 2008 (World Bank, 2011)

Figure 5-8 presents the alternative energy (includes hydropower and nuclear, geothermal, and solar power, among others) use as % of total energy use.

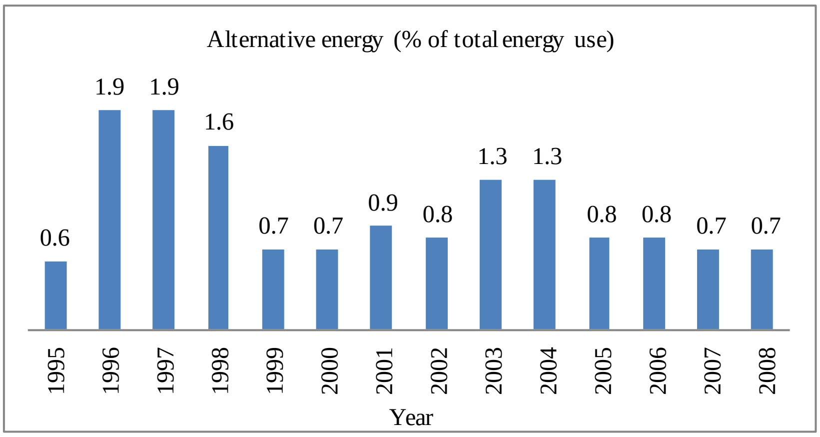


Figure 5-8 – Alternative energy use (% of total energy use) between 1995 and 2008 (World Bank, 2011)

In 2008, underlining the nation's strong dependence on fossil fuels, the share of oil, coal/peat, combustible renewables and waste, and gas in the TPES reached 72.6, 20.2, 3.3 and 3.2%, respectively. The share of hydroelectricity and geothermal/solar/wind in the TPES was of 0.5 and 0.2%, correspondingly (excluding electricity trades) (Fig 5-9).

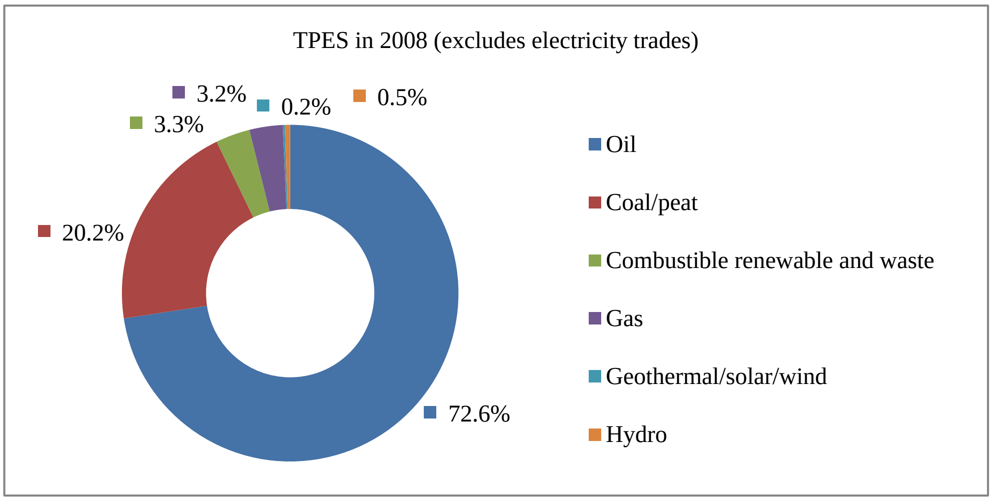


Figure 5-9 – TPES in 2008 (excludes electricity trades) (IEA, 2011i)

Table 5-5 presents the country's petroleum products consumption in the 2002 to 2008 time period.

Table 5-5 – Petroleum products consumption in Morocco between 2002 and 2008 (ESMAP, 2009)

kt/year	2002	2003	2004	2005	2006	2007	2008	Average growth 2002-2008
Propane	116	114	136	152	163	171	180	7.60%
Butane	1144	1226	1288	1347	1454	1596	1698	6.80%
Gasoline	399	385	380	376	388	417	482	3.20%
Jet	282	292	321	368	417	484	483	9.40%
Diesel	3133	3185	3303	3458	3555	3763	4144	4.40%
Fuel oil	1354	1464	1540	1874	1727	1628	2113	7.70%
Total	6429	6665	6968	7574	7703	8059	9100	6.00%
Yearly increase	n.a.	4%	5%	9%	2%	5%	13%	

Note: n.a. = not available

Currently there is only one operative refinery in Morocco: the Mohammedia refinery. The refinery is located nearby the western edge of the town of Mohammedia, about 30 km north of Casablanca, on the edge of the Atlantic Ocean. At present, it has a refining capacity of 125000 bpd. Table 5-6 presents the Moroccan refinery production in 2007.

Table 5-6 - Moroccan refinery production (1000 toe) in 2007 (Eurostat, 2010)

Total	of which				
	Gas/Diesel oil	Fuel oil	Gasoline	Naphta	Other
6105	2050	2221	391	628	816

An improvement in the Mohammdia refinery completed in 2009 increased its capacity and efficiency allowing for higher quality products. Therefore, the refinery's production margins are estimated to increase significantly. The petroleum downstream sector is in a mutation process since new topping at the oil refinery and the reinforcement of LPG storage capacities are planned (MEMME, 2009).

Given that the country has very limited fossil resources available, it depends highly on energy imports in order to fulfil its energy requirements and is the largest energy importer in North Africa (IEA, 2011i).

The country's energy import dependence has steadily risen over time as energy needs have increased. In 1995 the Moroccan net energy import was of 88.6% whereas by 2008 it reached 95.7% (Figure 5-10) (World Bank, 2011). Net energy imports are estimated as energy use less production, both measured in oil equivalents.

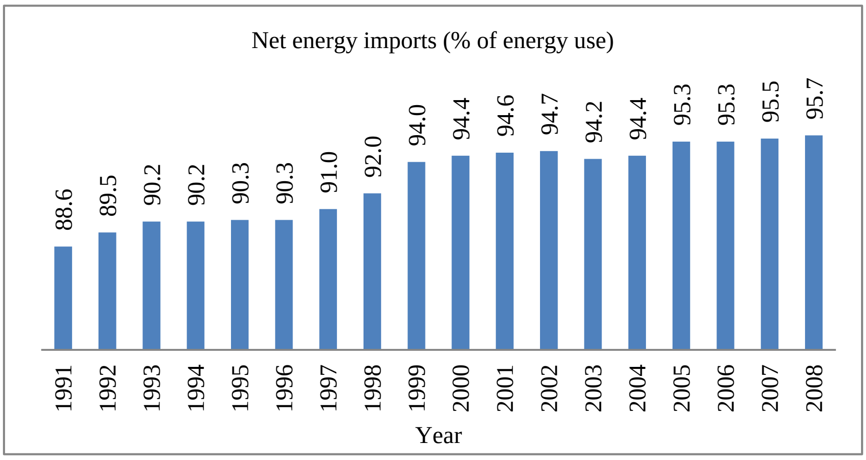


Figure 5-10 – Net energy imports (% of energy use) (World Bank, 2011)

The 2007 Moroccan energy imports by product are presented in Figure 5-11. It comprises primary energy and derived energy products, which have crossed the national boundaries, whether or not customs clearance has taken place. Oil and gas quantities of crude oil and oil products imported under processing agreements are included.

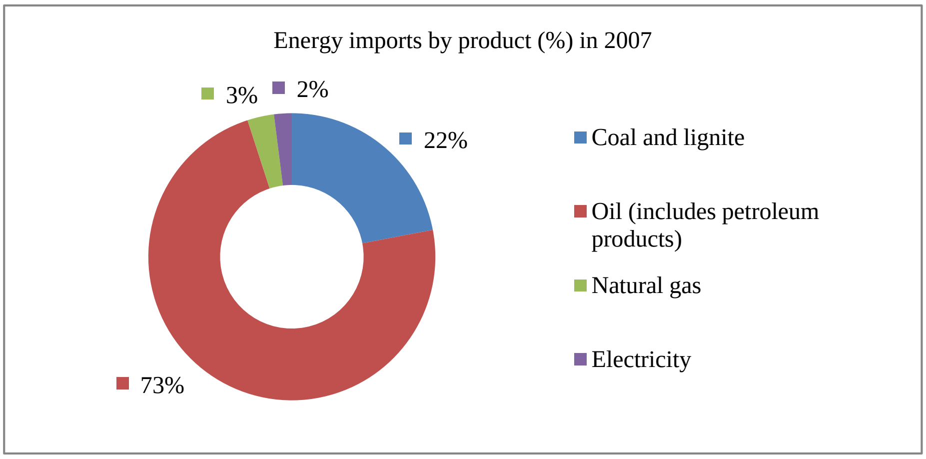


Figure 5-11 – Energy imports by product in 2007 (%) (Eurostat, 2010)

The Moroccan dependence on imported fossil fuels, predominantly oil, has a critical effect on both national and government budgets. The high oil prices recorded until mid-2008 were particularly burdensome and led to a widening of the Moroccan energy trade deficit. This strong dependence makes the country vulnerable to volatile and erratic fluctuations of the energy markets. Table 5-7 presents the Moroccan energy balance in 2008.

Table 5-7- 2008 Energy Balance (in thousand tonnes of oil equivalent (ktoe) on a net calorific value basis) (IEA, 2011i.)

	Coal and Peat	Crude Oil	Oil Products	Gas	Nuclear	Hydro	Wind/ Solar etc.	Combustible Renewables and Waste	Electricity	Heat	Total*
Production	0	8	0	44	0	80	26	480	0	0	637
Imports	2946	5613	5625	430	0	0	0	0	366	0	14980
Exports	0	0	-742	0	0	0	0	0	0	0	-742
International Marine Bunkers**	0	0	-13	0	0	0	0	0	0	0	-13
International Aviation Bunkers**	0	0	-516	0	0	0	0	0	0	0	-516
Stock Changes	0	162	468	0	0	0	0	0	0	0	631
TPES	**2946**	**5784**	**4822**	**474**	**0**	**80**	**26**	**480**	**366**	**0**	**14977**
Transfers	0	0	0	0	0	0	0	0	0	0	0
Statistical Differences	-313	1	-188	0	0	0	0	0	0	0	-501
Electricity Plants	-2597	0	-1191	-430	0	-80	-26	0	1791	0	-2533
CHP Plants	0	0	0	0	0	0	0	0	0	0	0
Heat Plants	0	0	0	0	0	0	0	0	0	0	0
Gas Works	0	0	0	0	0	0	0	0	0	0	0
Oil Refineries	0	-5785	5691	0	0	0	0	0	0	0	-94
Coal Transformation	0	0	0	0	0	0	0	0	0	0	0
Liquefaction Plants	0	0	0	0	0	0	0	0	0	0	0
Other Transformation	0	0	0	0	0	0	0	0	0	0	0
Energy Industry Own Use	0	0	-247	0	0	0	0	0	-94	0	-341

Losses	0	0	0	0	0	0	0	0	-196	0	-196
TFC	35	0	8886	44	0	0	0	480	1867	0	11313
Industry	35	0	1912	44	0	0	0	73	710	0	2774
Transport	0	0	3555	0	0	0	0	0	93	0	3649
Other	0	0	3067	0	0	0	0	407	1064	0	4538
Residential	0	0	1519	0	0	0	0	407	616	0	2542
Commercial and Public Services	0	0	0	0	0	0	0	0	336	0	336
Agriculture / Forestry	0	0	1528	0	0	0	0	0	112	0	1640
Fishing	0	0	0	0	0	0	0	0	0	0	0
Non-Specified	0	0	19	0	0	0	0	0	0	0	19
Non-Energy Use	0	0	352	0	0	0	0	0	0	0	352
- of which Petrochemical Feedstocks	0	0	0	0	0	0	0	0	0	0	0

*Totals may not add up due to rounding.

** International marine and aviation bunkers are included in transport for world totals.

5.3.1 Power Sector

5.3.1.1 Power Demand

With the PERG, Morocco took an ambitious step to generalize power access within rural areas excluded from this basic infrastructure. The rural electrification development (carried out either by linking them to the interconnected grid or in a decentralized manner, thanks to PV kits) is presented in Figure 5-12 (ONE, 2009).

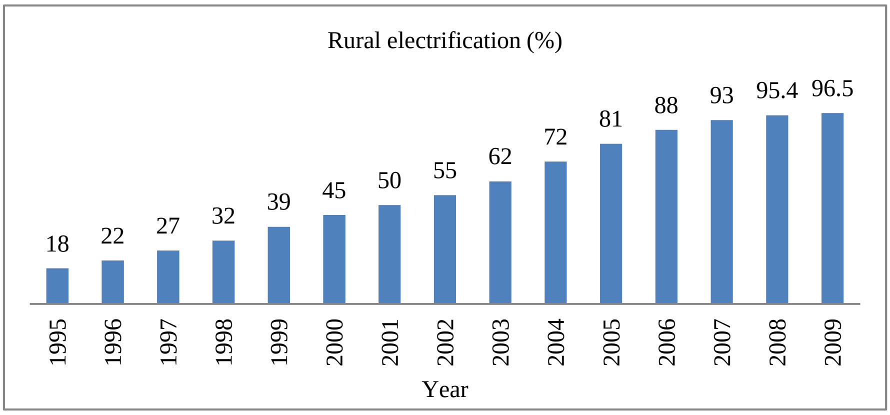
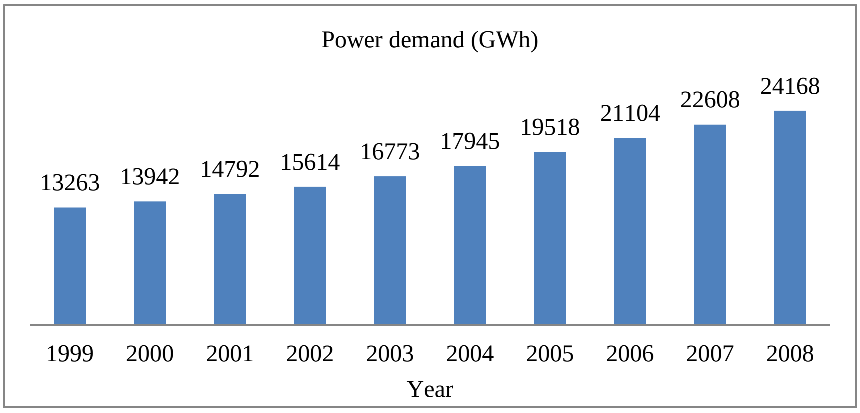


Figure 5-12 – Rural electrification evolution between 1995 and 2009 (ONE, 2009)

The Moroccan electricity demand has passed from approximately 13263 GWh in 1999 to 22608 GWh in 2007 which represents an average growth rate of about 6.9% (MEMEE, 2008). During this period the power demand peak has passed from 2394 to 3980 MW, which represents an annual increase of 6.6%. In 2008 the power demand has been of 24168 GWh representing, approximately, a 7.1% increase relatively to 2007 (Figure 5-13).

In 2009 the power demand reached nearly 25016 GWh, representing an approximately 4% increase compared to the demand recorded in the previous year (ONE, 2009).



Note: the power demand for 2008 is forecasted

Figure 5-13 – Power demand (GWh) evolution (MEMME, 2008)

Table 5-8 presents the daily load profile of 29 July 2008 and 28 July 2009. Figure 5-14 presents the load curve profiles of those days. In both years, the peak demand was late in the evening at 10 pm.

Table 5-8 - Load profiles of 29 July 2008 and 28 July 2009 (ONE, 2009)

Hour	Tuesday 29/07/2008 (MW)	Tuesday 28/07/2009 (MW)
1	3184	3509
2	2877	3194
3	2697	2996
4	2719	2895
5	2658	2906
6	2684	2915
7	2588	2845
8	2687	2954
9	3028	3347
10	3374	3657
11	3570	3888
12	3649	4032
13	3612	4008
14	3596	3918
15	3601	3896
16	3581	3876
17	3599	3841
18	3561	3826
19	3382	3659
20	3248	3582
21	3525	3808
22	4180	4375
23	3997	4196
24	3528	4008

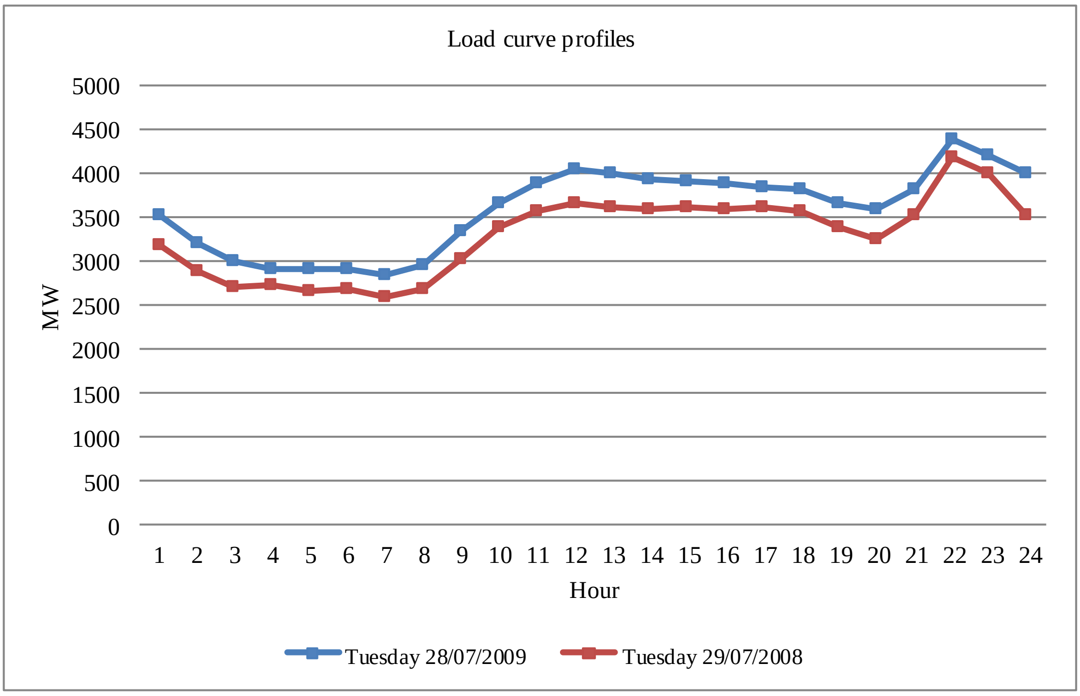


Figure 5-14 - Load curve profiles of 29 July 2008 and 28 July 2009 (ONE, 2009)

5.3.1.2 Power Supply

In the seventies the power sector depended on a considerable extent on hydroelectricity. Currently, the power generation is deeply based on fossil fuels with a small share from renewable energy sources (mainly hydroelectricity and wind power). Coal remains the principal fuel for electricity supply and more than 50% of the country's electricity demand has been supplied by coal power plants in the last decades.

Figure 5-15 presents the electricity production from oil sources (crude oil and petroleum products).

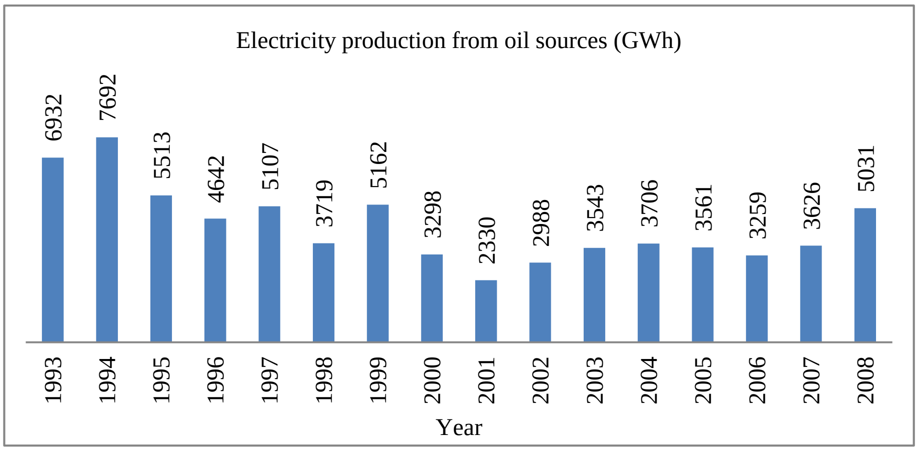


Figure 5-15 – Electricity production from oil sources (GWh) (World Bank, 2011)

Figure 5-16 presents the electricity production from coal sources. Coal refers to all coal and brown coal, both primary (including hard coal and lignite-brown coal) and derived fuels (including patent fuel, coke oven coke, gas coke, coke oven gas, and blast furnace gas). Peat is also included in this category.

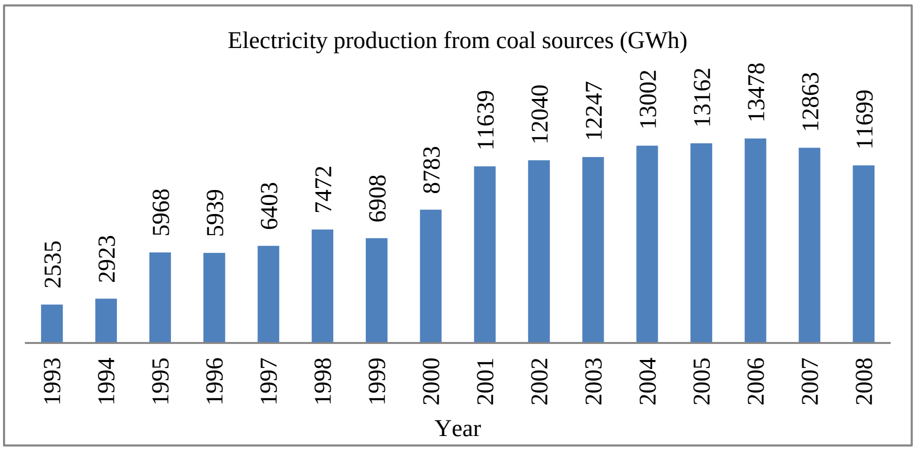


Figure 5-16 – Electricity production from coal sources (GWh) (World Bank, 2011)

Natural gas has been introduced in the primary energy supply mix in 2005.The electricity production from natural gas sources (excluding natural gas liquids) in 2005, 2006, 2007 and 2008 was of 2003 GWh, 2512 GWh, 2823 GWh and 2867 GWh, respectively (World Bank, 2011).

Figure 5-17 illustrates the share of the different fuel sources for power generation in 2006. In that year, coal, oil and gas accounted for approximately 68%, 14% and 13% respectively for power generation.

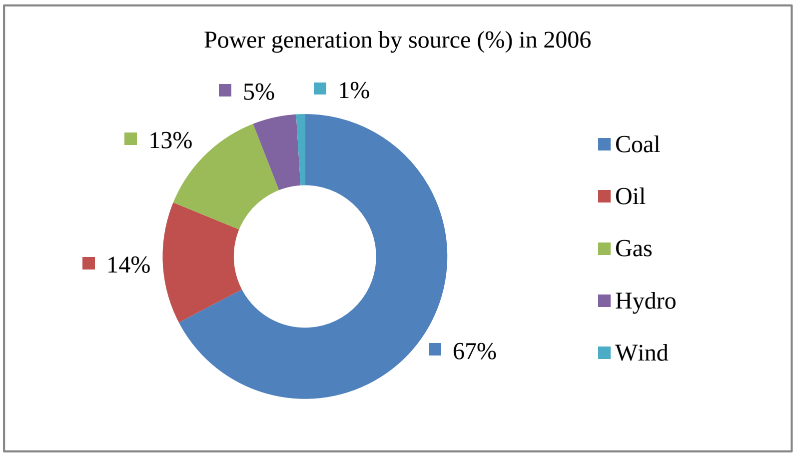


Figure 5-17 – Fuel sources for Moroccan power generation in 2006 (CIF, 2009)

The gap between the electricity demand and production has been fulfilled by the electricity energy imports (Figure 5-18).

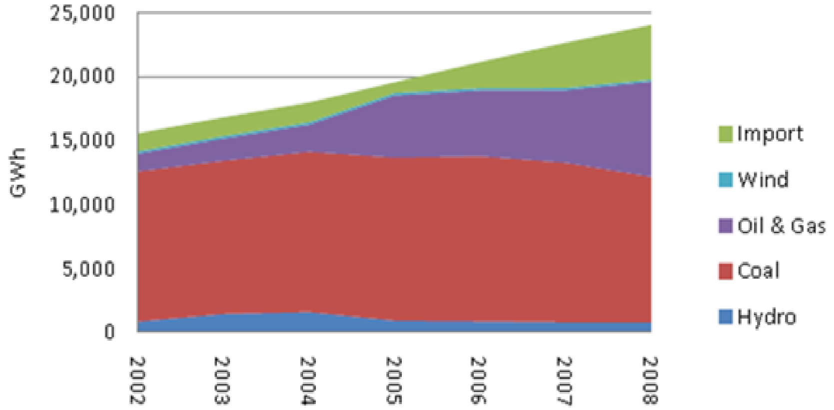


Figure 5-18 – Power supply by source within 2002 and 2008 (ESMAP, 2011)

5.3.1.3 Generation Capacity

Coal Fired Power Plants

In 2008 there were three coal fired power plants in Morocco, the Jorf Lasfar (JLEC) (4 Units, 1320 MW), the Mohammedia (300 MW generated by two coal-fired 150 MW steam turbines) and the Jerada plant (165 MW) (ONE, 2011).

The Jorf Lasfar plant was one of the three main projects within the *Production Concessionnel d'Electricité* (PCE) in the 1999 to 2007 period. In 2007, this power plant provided about 50% of the national electricity production. In 2008 the power plant production was 10022.8 GWh representing a 0.1% evolution relatively to 2007. An extension of the Jorf Lasfar power plant is expected to be commissioned between 2012 and 2013 (units 5-6, 700 MW). It will provide the much needed base load capacity to the country (ONE, 2009). The Mohammedia power plant was built in the early 1980s. In 2008 this power plant has produced 823.9 GWh. In that same year the Jerada power plant produced 815.1 GWh (COMET, 2011).

The ONE is planning to build a coal fired power plant with two new units (2 x 660 MW) in the Safi region. This project is conditioned by the construction of a port infrastructure, near the power plant, capable of receiving the fuel. This power plant inauguration is expected by the end of 2012 with a production of about 10 billion KWh per year, representing about 27% of the country's total demand by 2015. This coal fired power plant will use "Clean Coal" technologies to enhance EE and reduce the environmental impacts (ONE, 2009).

Combined Cycle Power Plants

The Tahaddart power station (385 MW) is the first combined cycle power plant built in the country. It opened on 20 January 2005. This installation consumes natural gas from the Maghreb Europe pipeline (MEMEE, 2008). It has a Siemens-manufactured steam turbine and gas turbine (nominal capacity of 400 MW). During 2009, this power plant supplied 2842550 MWh. It operated over 8440 hours at 95.4% capacity, and at an average operating capacity of 336.8 MW. This facility is the first power plant in the country to have its Environmental Management System certified by an internationally recognized body. The UNE-EN ISO 14001 Standard certifies that this power station operates in a way that protects the environment (PRP, 2011).

Planned to be completed by 2012 an Integrated Solar Combined Cycle power plant (ISCC), will have a 472 MW capacity. Solar energy is to provide 20 MW of these 472 MW. In 2009 this utility, partly operative, produced 210 GWh (ONE, 2009). This plant is located in Ain Béni Mathar (eastern Morocco) and is to be co-financed by ONE, the Global Environment Facility (GEF) and the AfDB (ONE, 2009).

Oil Fired Power Plants

There are several oil fired power plants in the country: the Mohammedia gas turbine (300 MW, 3 units x 100 MW), uses fuel oil number 2 as base fuel and produced 1684.8 GWh in 2008; the Kenitra power plant (300 MW, 4 units x 75 MW) which produced 1637.9 GWh in 2008 representing an evolution of 88.5% relatively to 2007; the Tan Tan power plant (116.5 MW, 7 diesel units) which had a net production of 17.8 GWh in 2007; the Agadir power plant (72 MW, 4 diesel units x 18 MW) which had a net production in 2007 of 6.4 GWh; the Daklha power plant (21 MW, 3 Units) which has entered in service in May 2002 and consumes diesel. This facility net production in 2007 was of 42.9 GWh; the Laayoune power plant, in the Moroccan Sahara, which had a net production of 97.2 GWh in 2007; the Tit Mellil power plant net production in 2007 was 150 GWh; the Tetouan 33 power plant (47.7 GWh net production in 2007); the Tetouan 20 power plant (produced 0.6 GWh in 2007); and the Tanger oil power plant (3.2 GWh net production in 2007) (COMET, 2011)

Renewable Energy Plants

Wind

In 2010 the wind-power capacity was 280 MW and consisted on the wind farms of Abdelkhalek Torres (50 MW) and Lafarge (30 MW) in Tetouan, on the Amogdoul (60 MW) in Essaouira and on the Tangier1 (140MW) (UNCCC, 2010).

Morocco has started a vast wind energy program, to support the advance of renewable energy and energy efficiency in the country. The Moroccan Integrated Wind Energy Project will allow the country to increase the wind power installed capacity, from 280 MW to 2000 MW in 2020 (AMDI, 2011). The new wind energy farms (1720 MW) are planned as follow:

- 720 MW under development in Tarfaya (300 MW), Akhfenir (200 MW), Bab El Oued-Laayoune (50 MW), Haouma (50 MW) and Jbel Khalladi (120 MW) (AMDI, 2011).
- 1000 MW planned in 5 new sites chosen for their abundant potential: Tanger 2 (150 MW), El BaidaKoudia in Tetouan (300 MW), Taza (150 MW), Tiskrad Laayoune (300 MW) and Boujdour (100 MW) (AMDI, 2011) (UNCCC, 2010).

The main goals of the wind energy program are: raise the share of wind power in the country energy balance to 14% by 2020; reach a production capacity from wind power of 2 GW and a yearly production capacity of 6600 GWh; spare 1.5 million ton of fuel per annum, matching the sum of 750 million U.S. dollars, and avoid of 5.6 million ton of CO_2 emissions per year (AMDI, 2011).

Solar

At this time, solar energy in Morocco is mostly used in rural and off-grid areas but the country presents an extensive variety of investment opportunities in the sector of thermal and photovoltaic solar energy, including the launch of the succeeding structuring programs:

- The Moroccan Project of Solar Energy that aims to reach 2000 MW of solar power capacity by 2020, over 10000 ha, within five locations (Table 5-9) (AMDI, 2011).

Table 5-9- Capacity and projected annual power generation of the 5 plants (AMDI, 2011) (ONE, 2009b)

Site	Capacity (MW)	Generation (GWh/yr)
Ouarzazate	500	1150
Ain Beni Mathar	400	835
Foum Al Oued	500	1150
Boujdour	100	230
Sebkhat Tah	500	1040

These facilities will use CSP and PV technologies.

This program will increase by 14% the share of solar energy in total electricity capacity by 2020 and prevent the emission of 3.7 million tons of CO_2 per year. Additionally, this project will avoid 1 million toe per year, corresponding to a 500 million dollars saving (ONE, 2009b).

- The Development Program of the Moroccan market for solar water heaters (PROMASOL) (AMDI, 2011).

This project includes the installation of 440000 m^2 and 1.7 million m^2 of thermal solar sensors in 2012 and in 2020 respectively. By 2020, the thermal energy is projected to reach 1190 GWh/yr. This program will prevent the emission of 920000 tons of CO_2 annually and generate 920 permanent jobs (AMDI, 2011).

These two solar projects were planned to fall under the criteria of Clean Development Mechanism (CDM) (AMDI, 2011).

Hydro

At the end of 2009 the hydro-power installed capacity reached 1748 MW and consisted on hydro-turbines (1284 MW) and on hydro-pumping (464 MW) (ONE, 2009).

The country is focused on the development decentralized small hydropower projects for remote areas. Hydroelectric power does not automatically involve a large dam and some power plants use a small canal to channel river water through a turbine and several of these projects are now under progress by ADEREE.

Changes in precipitation and surface runoff intensely affect the extent of hydroelectric power generated. The rainfalls can vary considerably from one year to another. Table 5-10 presents the country's hydroelectric power plants net production between 2000 and 2008.

Table 5-10 - Moroccan's hydroelectric power plants net production between 2000 and 2008 (COMET, 2011)

Year	Net Production (GWh)
2000	704.728
2001	862.275
2002	842.020
2003	1441.102
2004	1600.303
2005	1411.815
2006	1585.255
2007	1318.127
2008	1359.808

Table 5-11 presents the existing hydro power plants as of December 31, 2008, its watercourse, total unit and its net production.

Table 5-11 - Existing power plants as of December 31, 2008, its watercourse, total unit and its net production (COMET, 2011)

Power plant	Watercourse	Number of Units	Net Production (GWh) in 2008
Bine el Ouidane	Oued	3	94.2
Afourer	El Abid	2	227.8
Moulay Youssef	Tassaout	2	18.7
Hassan 1º	Lakhdar	1	57.5
STEP Afourer	Oued El Abid	2	443.7

Power plant	Watercourse	Number of Units	Net Production (GWh) in 2008
El Hansali	Oum er rbia	1	38.1
Ait Messaoud		2	10.6
Al Massira		2	10.1
Imfout		2	12.6
Daourat Bou		2	2.2
Sidi said maachou		4	0.0
Kasba Zidania		2	0.2
Lalla Takerkoust	N'fis	2	6.5
Mansour Ed dahbi	Draa	2	18.4
El Wahda	Ouargha	3	97.5
El Kensera	Beht	2	10.4
Idriss 1	Innaouene	2	30.0
Allal el Fassi	Sebou	3	162.7
Oued el Makhazine	Loukkos	1	13.8
Lau	Lau	4	20.2
Taurart	Talambot	2	5.4
Mohamed El Khamis	Moulouya	1	69.7
Bou Areg		1	8.2
Fes Amont	Cheracher	3	1.4
Fes Aval	Boukhrareb	2	0.0
Sefrou			0.0
Taza	Taza	2	0.3
Meknes	Boufekrane	2	0.0

Biomass

According to ONE, in 2020 the biomass capacity will be around 950 MW (corresponds to a 2 billion euro investment) (DOC DULCE) (MEMEE, 2008c). The Green Morocco strategy to boost agricultural production and new regulations for waste management stands for an additional 400 MW capacity by 2030. In 2002 an U.S. consortium (GESI-Edgeboro-SADAT) won a government tender for the management of the first controlled landfill in Fes (MLRH, 2011). The 10 year contract of construction and operation of this landfill has been extended in 2007 for another 20 years to recover and reuse the biogas from the landfill allowing an estimated 3 MW generation that could be used for public lighting (ECOMED, 2011).

Nuclear Power Plants

The ONE ponders the nuclear power option as one of the feasible solutions to meet the future power demand of Morocco. In the beginning of the 1980s, the ONE commenced site and technical-economic viability assessments for the first nuclear power plant in the country in the framework of a settlement signed with SOFRATOME (French company), with the technical support of the International Atomic Energy Agency (IAEA) (IAEA, 2010).

The site of Sidi Boulbra, located on the Moroccan Atlantic coast between the cities of Safi and Essaouira, was elected and qualified as a capable site to have a nuclear power plant under the necessary nuclear safety conditions. Sidi Boulbra site might take up to 4 units of 1000 MW each (IAEA, 2010).

The Moroccan governmental strategy has intentions to introduce nuclear power by 2020-2025 (IAEA, 2010).

The national strategy concerning fuel exploration and radioactive waste management has not been decided so far as it depends on other several aspects, such as the reactor type and the viability of uranium extraction (IAEA, 2010).

Combined Heat Power Plants

Presently, there are no CHP plants in the country.

Total Installed Capacity

In 2005 the installed capacity totaled 5252 MW (Table 5-12). The 2005 thermal production is presented in table 5-13.

Table 5-12 - Installed capacity at the end of 2005 (MW) (ONE, 2005)

Hydro (turbines)	1265
Hydro (pumping)	464
Total Hydro	**1729**
Steam thermal power plants	2385
* Fuel	600
* Coal	1785
Gas turbines	615
Tahaddart	400
Diesel	69
Total Thermal	**3469**
Wind (50 MW from CED)	**54**
Total	**5252**

Table 5-13- Moroccan thermal production (GWh) in 2005 (ONE, 2005)

Coal	JLEC	10028
	Mohammedia	1641
	Jerada	1062
Fuel	Mohammedia	1248
	Kenitra	1100
	Gas turbines	398
	Diesel	58
	Gasoil	3
Natural gas	Tahaddart	2003

By the end of 2009 the installed capacity reached 6135 MW (Table) against the 5292 MW capacity recorded in 2008. This 15.9% increase has been due to the partial operation of the Ain Béni Mathar power plant (300 MW) and to the Tangier wind farm in (107 MW) and the operation of the diesel plant at Tan Tan (116 MW), the Mohammedia gas turbines (3x100 MW) and the hydro plant at Tanafnit (18 MW) (ONE, 2009). Table 5-14 presents the installed capacity by the end of 2009.

Table 5-14- Installed capacity at the end of 2009 (MW) (ONE, 2009)

Hydro (turbines)	1284
Hydro (pumping)	464
Total Hydro	**1748**
Steam thermal power plants	1065
* Fuel (Mohammedia & Kénitra)	600
* Coal (Mohammedia & Jerada)	465
Gas turbines (open cycle)	915 (6x20 MW + 15x33 MW + 3x100 MW)
Diesel	186
JLEC (Coal)	1320
Tahaddart	380
Ain Béni Mathar combined cycle power plant (phase 1)	300
Total Thermal	**4166**
Wind ONE	171
Wind CED	50
Total Wind	**222**
Total	**6135**

Table 5-15 presents the national production and imports of electricity over 10 years; between 1999 and 2008 (data for 2008 is a forecast).

Table 5-15– Moroccan electricity production and imports between 1999 and 2008 (MEMEE, 2008)

GWh	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
National Production	11392	11541	13153	14104	15301	16383	19158	19823	19638	20582
Thermal	10575	10772	12091	13068	13657	14584	17540	18054	18041	7775
Hydro	817	705	856	842	1441	1600	1412	1586	1318	9898
Wind	-	64	206	194	203	199	206	183	279	2909
Importation	1846	2363	1564	1392	1438	1535	814	2027	3507	4214

Note: 2008 data is forecasted

The national production at the end of December 2009 was approximately 20935 GWh. This production satisfied about 84% of the electricity demand in that year.

5.3.1.4 Electricity Transmission

With a grid consisting of HV/VHV lines (60, 150, 225 and 400 kV) ONE is responsible for the power transmission (ONE, 2009).

In order to sustain the rising power demand, the investments within the power sector from 1999 to 2008, reached 53 billion DH, and have covered the PERG, the reinforcement of the production base, the development of the transportation network and the improvement of the distribution infrastructure (MEMEE, 2008).

Between 1999 and 2008, the ONE continued its program for the reinforcement of the national transmission network which includes the interconnections with neighbour countries. These works aim to reinforce the reliability and the security of the transport network and the increase of trade with neighbour countries, with a view to the opening of the national electricity market to the competition and its integration in the Euro-Maghreb market. As a result, in this period, the works in the very high and high voltage transmission lines exceeded 4500 Km (MEMEE, 2008).

Morocco has electrical interconnections with Spain and Algeria. The submarine electrical cable connection with Spain was established in 1997 and provides an exchange of 1400 MW. Morocco’s electricity network is connected with the networks of Algeria and Tunisia; these three countries formed the COMELEC (*Comité Maghrébin de l’Electricité*) in 1975 to promote electricity exchanges and they were later joined by Libya and Mauritania. The electrical grid interconnection with Algeria was established in 1992 and ensures 1200 MW (MEMME, 2008b).

The reinforcement of the Morocco-Spain interconnection became necessary in order to allow an increase in the import capacity. The start of the operation of the 2nd interconnection between Morocco and Spain occurred in June 2006, allowing an increase in the import capacity to 700 MW. Morocco, owing to its special geographical position at the heart of an international energy crossroads is set to become a key hub of the increasing power exchange between the countries around the Mediterranean, thanks to the reinforcement of the interconnections it has established with Spain and Algeria.

In 2009 the transmission network total length has reached 20350 km. Table 5-16 presents the recent transmission network developments.

Table 5-16 - Recent transmission network developments (ONE, 2009)

	2008	2009	Growth
Total length (km)	19578	20350	4%
400 KV line (km)	1284	1361	6%
225 KV line (km)	7607	7724	2%
150 KV line (km)	147	147	0%
60 KV line (km)	10540	11118	5%

Figure 5-19 presents the power transmission and distribution losses (% of output). Electric power transmission and distribution losses include losses in transmission between sources of supply and points of distribution and in the distribution to consumers, including pilferage.

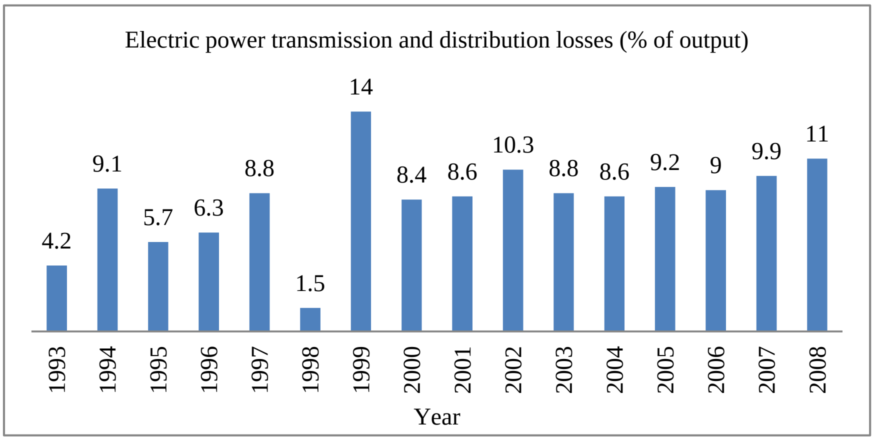


Figure 5-19 - Power transmission and distribution losses as % of output between 1993 and 2008 (World Bank, 2011)

In 2005 and 2008 the electric power transmission and distribution losses have been of 1837 GWh and 2281 GWh, respectively (World Bank, 2011).

5.3.1.5 Electricity Distribution

Mainly the ONE and some private operators in the big cities of the country (LYDEC in Casablanca, REDAL in Rabat, AMENDIS in Tanger/Tetouan) are responsible for the power distribution. According to ONE, in 2008 the transport losses of its distribution grid were at 4.7% of the total injected electricity.

Electricity prices are subsidized both directly by transfers to cover operating costs and indirectly by low prices for fuel oil. The retail prices however are still relatively high by regional standards. The rates are set by ministerial decree. Table 5-17 presents the residential electricity prices.

Table 5-17 - Residential electricity prices (RECREEE, 2010)

Consumption per month	Price Dh/kWh
0 - 100 kWh	0.9010
101 - 200 kWh	0.9689
201 - 500 kWh	1.0541
> 500 kWh	1.4407

Rural consumers are charged through a pre-paid meter system. The customer can purchase the wanted amount via rechargeable cards. The tariffs are distinguished in a different way, as shown in the table 5-18.

Table 5-18 - Residential electricity prices for rural consumers (RECREEE, 2010)

Power bracket	Price Dh/kWh
Power less or equal to 1 kW	1.0700
Power between 1 kW and 2 kW	1.1021
Power between 2 kW and 3 kW	1.1449
Power above 3 kW	1.3910

Business customers are allowed to select from different tariff structures. For HV customers there is a choice between a tariff based on a subscribed capacity plus time-of-day unit charges or a tariff comprising three price options calculated according to the annual duration of power usage. The latter tariff is shown in the table 5-19.

Table 5-19 - Electricity prices for HV consumers (option of annual duration) (RECREEE, 2010)

Load hours	Capacity charge Dh/kW/yr	Dh/kWh		
		Peak time	Full time	Off peak
VLU	1259.57	0.5974	0.4791	0.4376
MU	504.26	0.9517	0.6028	0.4376
SU	252.13	1.2550	0.7011	0.4572

5.3.1.6 Domestic Energy Resources

Fossil Fuel Resources

- **Oil**

Though Morocco's proven oil deposits are small (750000 barrels as of January 1st 2009), there is reasonable evidence that there could still be vast undiscovered oil (and gas) reserves (RECREEE, 2010).Over the last years, Morocco has effectively pushed for the exploration of possible oil (and gas) deposits. A study carried out in 1999 indicated that the offshore basin nearby Tarfaya (near Morocco's southern Saharan provinces) would be the most suitable area for oil reserves (RECREEE, 2010). The Gharb and the Essaouira basin as well as near the Rif, a mountainous region in the north of Morocco, are thought to be the most promising onshore regions. The Ireland's oil company Circle Oil reported a successful drilling and testing of a gas well in the Gharb region northeast of Rabat.

Regarding oil shale, Morocco has the sixth largest proven reserves in the world. Morocco's total in place oil shale reserves are estimated at around 50 billion barrels (as of 2006) (RECREEE, 2010). The major deposits, located near Tarfaya and Timahdit, are well explored and are the most probable to initiate commercial production in the near future. The Timahdit deposit, sited about 250 km southeast of Rabat zone, has an estimated 16.1 billion barrels of oil in place. Tarfaya contains about 22.7 billion barrels of oil.

To become less dependent on energy imports and in order to diversify its primary energy sources Morocco has taken the first step headed for commercially exploring its oil shale reserves: for 2008-2012 as part of the *Plan Nationale des Actions Prioritaires* (PNAP) the government plans to invest DH 32 million (US$2008 4.4 million) in the sector and is currently establishing a regulatory framework. There is also a pilot project for oil shale-based power generation ongoing in Tarfaya.

In 2004 the main crude oil suppliers have been Saudi Arabia, Russia, Iran and Iraq.

- **Coal**

The country is heavily dependent on coal imports since the closure of the coal mine of Jerada in 2001. Coal is mainly imported from the United States, Colombia and South Africa (RECREEE, 2010). According to the National Energy Strategy 2020-2030 published in 2009 by the government, coal will continue to be the primary fossil fuel used for power generation in the next decades (RECREEE, 2010).

- **Natural gas**

Identically to its oil reserves, Morocco's proven natural gas reserves are small, around 1.5 billion m^3 as of January 1st 2009 (RECREEE, 2010). ONHYM supervises all natural gas related explorations, surveys and drillings. Considered as a strategic platform for energy transit, Morocco plays a major role in the transportation of gas from Algeria to Spain as the Maghreb-Europe gas pipeline links the Hassi R'mel field in Algeria via Morocco with Spain where it feeds into the European gas grid.

It is intended that the natural gas share in the TPES reach 20% until 2020. A LNG (liquefied natural gas) terminal will be built by 2015. It will have an initial capacity of 5 BCM; this option is to be realized if supply is secured. This LNG Terminal is planned to be at Jorf Lasfar (Atlantic coast) or Nador (Mediterranean Sea) – 5 BCM in 2015, 10 BCM in 2018 (MEMME, 2009).

- **Uranium**

Morocco has great quantities of uranium in its phosphates. This resource may well be useful in the future if viable competitive mechanisms are established for its extraction. The estimated availability of uranium in the Moroccan phosphates, according to IAEA's latest assessments, is of around 6.9 million ton (IAEA, 2010).

Renewable Energy Resources

- **Wind**

Morocco has an excellent wind energy potential (of about 6000MW a year) mainly in the North, and in the South (MEMEE, 2008b). In Tangier and Tetouan, the annual average wind speed ranges between 9.5m/s and 11 m/s at 40 meters elevation. In Tarfaya, Taza and Dakhla the annual average wind speed ranges between 7.5 m/s and 9.5 m/s at 40 meters (MEMEE, 2010). Between 2000 and 2008, more than 50 measurement stations were installed by the *Centre de Développement des Energies Renouvelables* (CDER). Figure 5-20 presents the country's wind map.

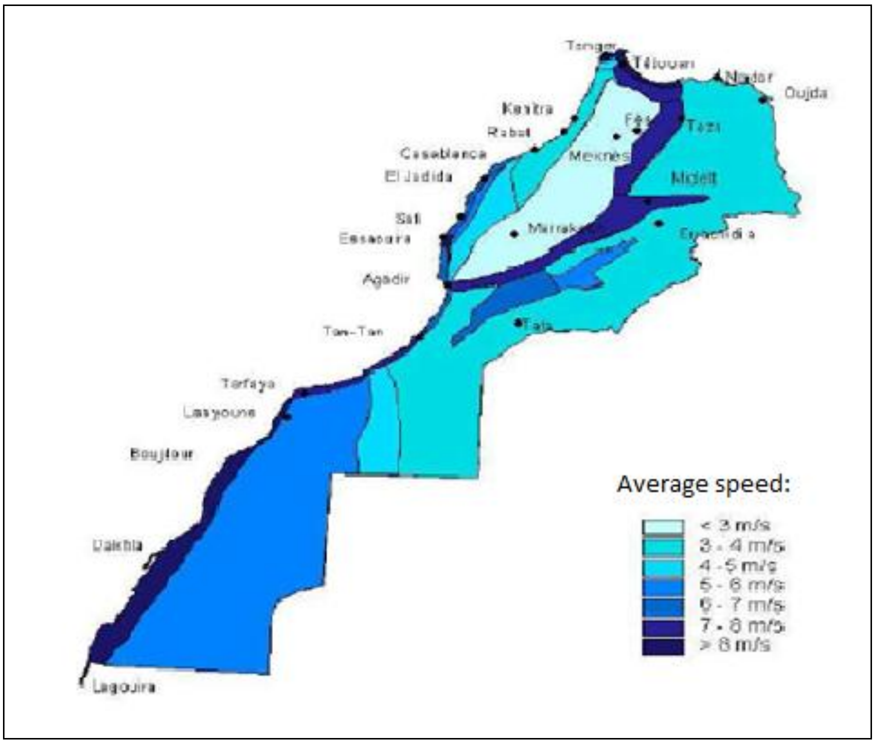


Figure 5-20 - Morocco's wind map (CDER, 2010)

The country, given appropriate conditions, might possibly support a total capacity of around 6000 MW a year (MEMEE, 2008b).

- **Solar**

Morocco possesses abundant solar resources. The annual sunshine averages 3000 hours, equivalent to an almost 5.3 kWh/m^2/day potential (UNCCC, 2010). Figure 5-21 presents the country's solar potential.

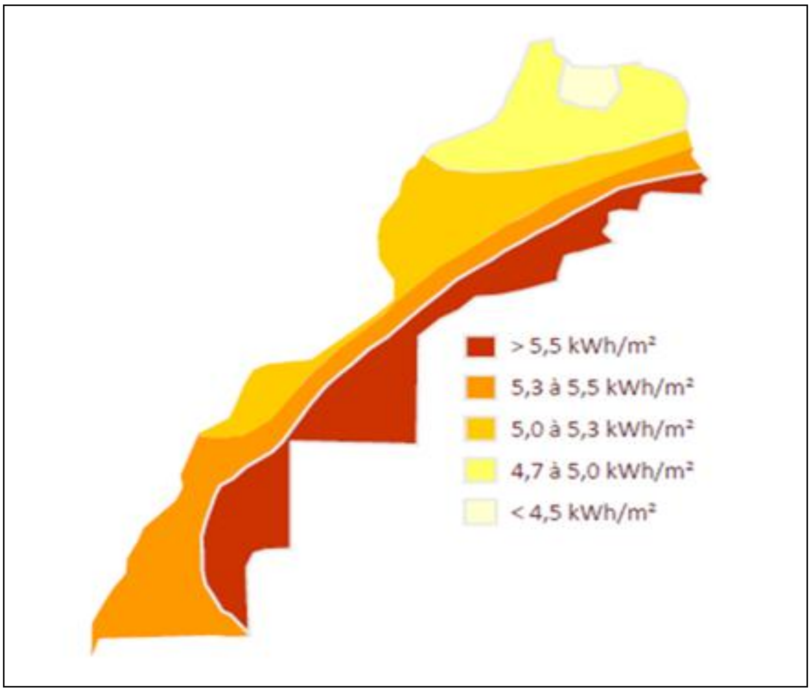


Figure 5-21 - Morocco solar potential (MEMEE, 2010)

- **Geothermal**

There seems to be some geothermal potential in the northeast of the country and in the Sahara sedimentary basins (Figure 5-22). Currently, geothermal direct use is mainly limited to balneology, swimming pools and potable water bottling (DOC).

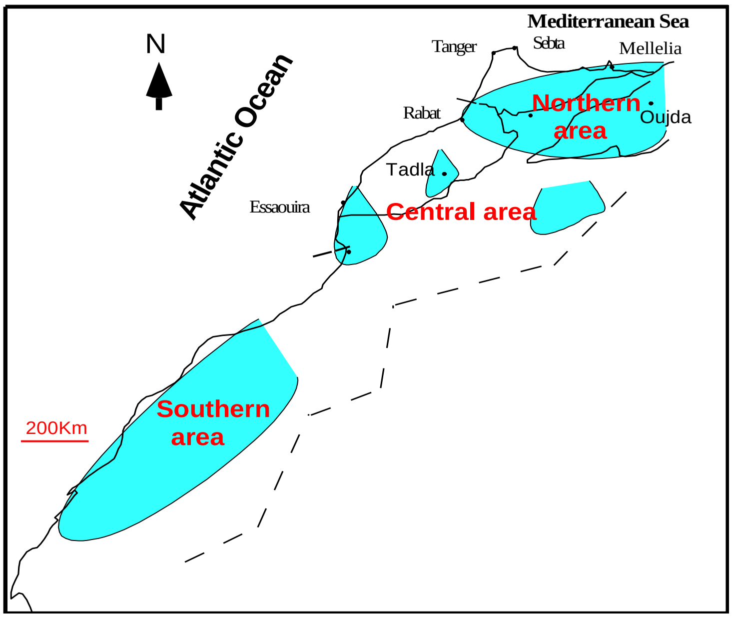


Figure 5-22 - Potential geothermal fields in Morocco (Zarhoule, 2011)

- **Biomass**

The biomass potential is based on ample agricultural resources, comprising wide areas for livestock breading (2.6 million cattle, 16.3 million sheep and 5.3 million goats).

- **Hydro**

There are potentially, 200 sites to explore for hydropower in the country (COMET, 2011) (MEMEE, 2008b)

- **Ocean Energy (tidal and wave)**

In the medium term, some niche market might be present.

5.3.2 Energy End-use Sectors

5.3.2.1 Transport Sector

The transport sector is a major energy consumer in Morocco (CIF, 2011). Figure 5-23 presents the energy consumption of the transport sector as % of the total final energy consumption from 2004 to 2007.

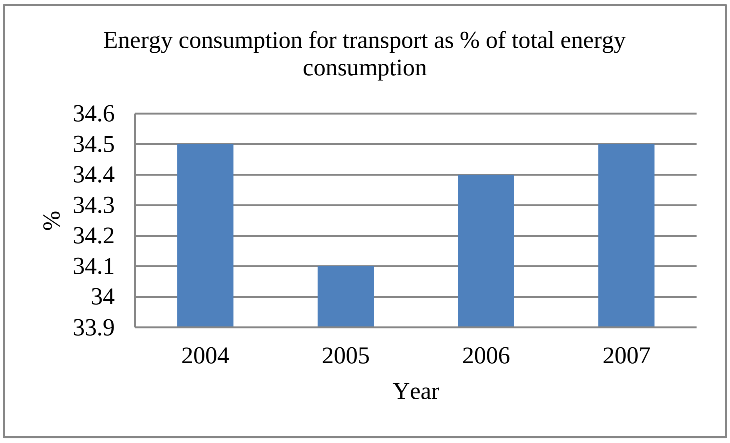


Figure 5-23 - Energy consumption by the transport sector as % of total final energy consumption (Eurostat, 2010)

In 2008, on a net calorific value basis, the transport sector consumed 3555 ktoe of oil products, and 93 ktoe of electricity (IEA, 2011i).

Energy consumption in the transport sector has increased approximately 5% per annum in recent years. Road transport is by far the main mode of transport, accounting for about 95% of all internal passenger transport volume, 70% of freight transport and 98% of the sector's energy use (CIF, 2011).

Table 5-20 presents the length of the main transport networks in 2000 and 2008.

Table 5-20 - Lenght of the main transport networks (Km) (Eurostat, 2010)

2000			2008		
Roads		Rail	Roads		Rail
Total	Motorways		Total	Motarways	
57652	425	1907	57852	866	1907

It was estimated that around 420000 ton of gasoline and 2.2 million ton of diesel were consumed in 2007 by the transport sector. Gasoline and diesel have been of reduced quality and around 30% to 40% of the consumed gasoline in 2007 was leaded and about 95% of the consumed diesel had more than 10000 ppm of Sulphur. In 2009 the Government banned leaded gasoline and imposed firm norms on the diesel consumed in the transport sector, including a maximum Sulphur content of 50 ppm (the diesel 50 ppm replaced the diesel 350 in February 2009 and the ordinary diesel in April 2009) (World Bank, 2011a).

Moroccan fuel prices are among the highest of the MENA region. The gasoline price is about US$1.35/liter and therefore includes a considerable net tax. The diesel price, at about US$0.9/liter is somewhat above the cost recovery level (World Bank, 2011a).

Between 1993 and 2003, the number of cars in circulation increased by 36%. Aside from walking, travel in urban areas takes place predominantly in private cars and taxis. Consequently, rush hour travel conditions in urban areas are frequently problematic. The Urban Transport Master Plan has recognized that in Casablanca more than one-third of the intersections examined are presently very congested. Additionally, several indicators point to a substantial intensification in the rate of vehicle ownership (World Bank, 2011a).

Table 5-21 presents the passenger cars (1000) average annual growth rate between 2000 and 2006 and the road goods vehicles (1000) average annual growth rate between 2000 and 2004.

Table 5-21 - Number of passenger cars (1000), of road goods vehicles (1000) and of buses and coaches (1000) (Eurostat, 2010)

	2000	2002	2004	2006	Average annual growth rate (%)
Number of passenger cars (1000)	1211	1296	1384	1492	3.5
Number of road goods vehicles (1000)	400	428	450	n.a.	3.0
Number of buses and coaches (1000)	15	16	16	17	2.1

Note: n.a. = not available

In Casablanca, the number of cars is increasing about 4.5% per year on average and is projected to increase almost 50% between 2010 and 2020 (World Bank, 2011a).

- Rail infrastructure

Table 5-22 presents the number of locomotives (include tractive railway vehicles with a power of 110 kW and above at the draw hook equipped with prime mover and motor or with motor only used for hauling railway vehicles) and goods transport wagons (railway freight wagon normally intended for the transport of goods) in 2008.

Table 5-22- Number of locomotives and goods transport wagons in 2008 (1000) (Eurostat, 2010)

Number of locomotives (1000)	Number of goods transport wagons (1000)
221	6040

Table 5-23 presents the rail freight transport (covers any goods moved by rail vehicles, this includes all packing and equipment, such as containers, swap-bodies or pallets as well as road goods vehicles carried by rail).

Table 5-23- Rail freight transport (million tkm) (Eurostat, 2010)

2000	2002	2004	2006	2008	Average annual growth rate (%)
4650	4973	5563	5873	4986	0.9

- Airport infrastructure

There are 24 airports in the country: 15 international airports, 6 domestic airports and 3 airports that serve as secondary platforms (COMET, 2011). Since the 2003 liberalization of air transport, the country has seen several low-cost companies entering the market, and Morocco's signing of an open skies agreement with the EU in 2006 has furthered this trend. In 2007 the consumption of kerosene jet fuels reached 501000 toe (Eurostat, 2010).

In 2002, 2008 and 2009 there were 22, 44 and 45 commercial airlines respectively (excluding low-cost airlines). In 2002 there were 91.3 thousands commercial flights and in 2008 there were 136.1 thousands (COMET, 2011).

- Maritime transport

The country has 30 ports, 12 are commercial, 12 are dedicated fishing and 6 pleasure ports. Maritime transport accounts for 95% of Morocco's foreign trade. Casablanca port is the major one and it handles nearly 36% of the country's maritime traffic and approximately 86% of container traffic. The Tanger Med port is another key trade facility. The opening of its first terminal, conceded to APM Terminals Tangier, has been in July 2007. By the end of April 2008 this port had accommodated nearly 200 stopovers and treated nearly 275000 twenty-foot containers (COMET, 2011).

5.3.2.2 Industry Sector

The energy consumption in industry as % of total final energy consumption from 2004 to 2007 is presented in Figure 5-24.

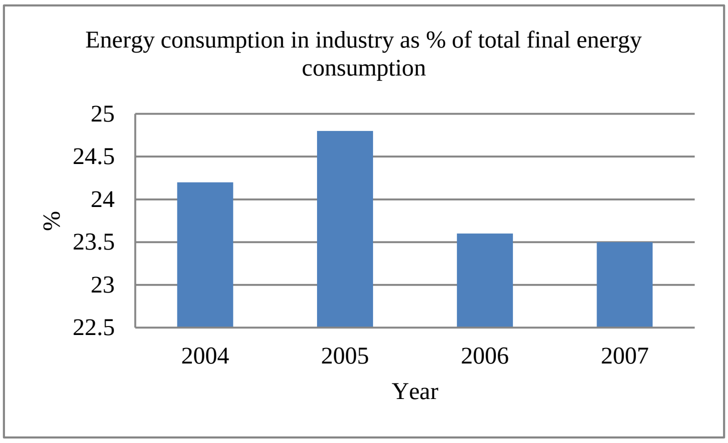
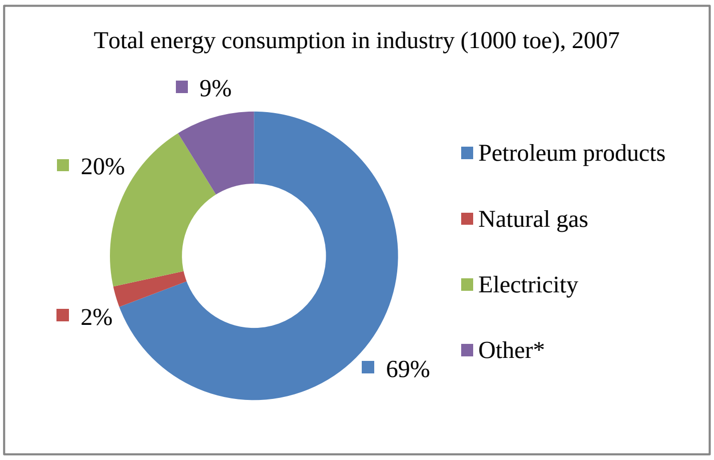


Figure 5-24 – Energy consumption in industry as % of total final energy consumption (Eurostat, 2010)

Figure 5-25 presents the industrial sector total energy consumption in 2007.



* Other includes solid fuels and renewable energy.

Figure 5-25 – Total energy consumption in industry (1000 toe), 2007 (Eurostat, 2010)

In 2008, on a net calorific value basis, the industrial sector consumed 1912 ktoe of oil products, 73 Ktoe of combustible renewables and waste, 44 ktoe of gas, 35 Ktoe of coal and peat products and 710 ktoe of electricity (IEA, 2011i).

The energy demand in the industrial sector is concentrated in three main segments: cement, phosphates and sugar units. Their energy use is estimated to increase substantially in the upcoming decades, from around 1600 Mtoe in 2005 to 5200 Mtoe in 2030 (CIF, 2011). Table 5-24 presents a projection for the cement sector production and consumption development until 2030 (from the Second National Communication to the UN Framework Convention on Climate Change).

Table 5-24 - Projection of the cement production and consumption until 2030 (SNC, 2010)

kton	1994	2000	2004	2005	2010	2015	2020	2025	2030
Production	6284	7625.8	9796.3	10420	14190	19323	26312	35830	48791
Consumption per capita	241.01	265.66	327.72	345.36	445.50	576.74	749.38	977.97	1284.17

The mineral industry is a major source of revenue. Morocco has 75% of the world's phosphate reserves, is the world's leading exporter (28% of the global market) and the third-largest producer (20% of global production). Phosphate rock is mined in several regions of the country. The most actively mined area is Khouribga, which is the single largest producing phosphate mine in the world. The two open pit mining operations at Khouribga account for nearly 50% of all phosphate rock mined in the country. The reserves of phosphate rocks are estimated to be approximately 20 billion tons (GAA, 2008). The *Office Chérifien des Phosphates* (OCP) has plans to intensify the production capacity significantly in the future. Increasing efficiency of the phosphate process will reduce net energy use and emissions. Table 5-25 presents the phosphate rock production in Morocco.

Table 5-25 - Phosphate rock production (million metric ton) (Kent, J.A., 2007)

Year	1980	1990	2000	2001	2002	2003
Production	18.8	21.2	21.6	21.8	23.0	23.3

5.3.2.3 Residential and Commercial Sectors

The energy consumption in households and other sectors as % of total final energy consumption is presented in Figure 5-26.

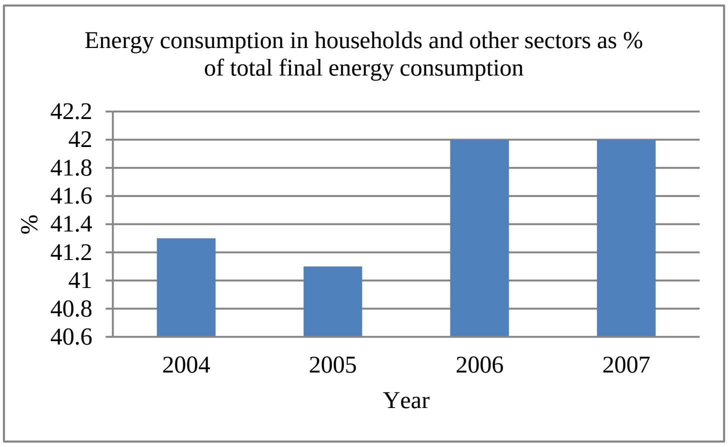


Figure 5-26 – Energy consumption in households and other sectors as % of total final energy consumption (Eurostat, 2010)

Table 5-26 presents the consumption of petroleum products by households, by product (1000 toe), in 2007.

Table 5-26 - Consumption of petroleum products by households, by product (1000 toe), in 2007 (Eurostat, 2010)

Total petroleum products	of which		
	LPG	Gas/Diesel Oil	Others
1363	1340	13	10

In 2008, on a net calorific value basis, the residential sector consumed 1519 ktoe of oil products, 407 ktoe of combustible renewables and waste and 616 ktoe of electricity. In that year, on a net calorific value basis, the commercial and public services sector consumed 336 ktoe of electricity (IEA, 2011i).

Morocco has one of the MENA's highest residential electricity prices (IEA, 2010b). Figure 5-27 presents the usage split of the final energy consumption within the residential and commercial sectors by 2005. The figure indicates that cooking is the main energy consumer within these sectors.

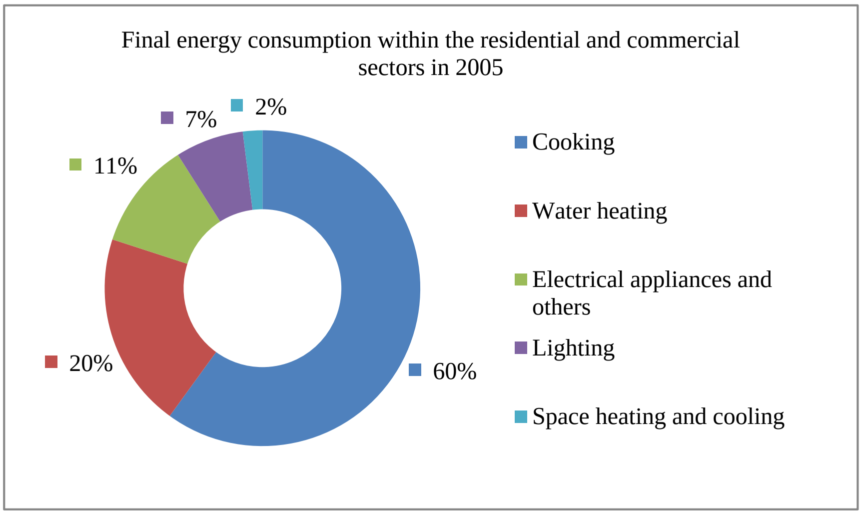


Figure 5-27 – Usage split of the final energy consumption within the residential and industrial sectors in 2005 (ESMAP, 2009)

5.3.2.4 Agriculture Sector

In 2008, on a net calorific value basis, the agriculture/forestry sector consumed 1528 ktoe of oil products and 112 ktoe of electricity (IEA, 2011i).

5.3.2.5 Power Consumption by Sector

The most electricity-consuming sectors are the industrial and residential with a 38% and 33% share, recorded in 2008, respectively (Figure 5-28).

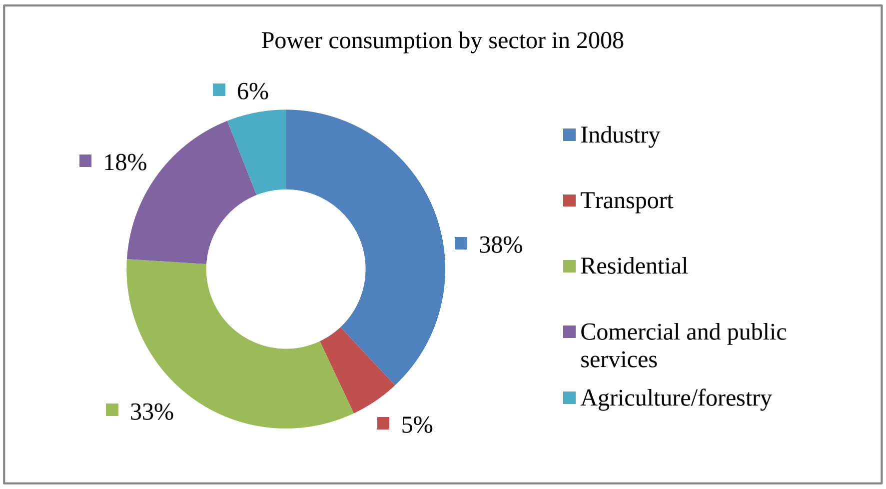


Figure 5-28 – Power consumption by sector in 2008 (IEA, 2011i)

The industry sector consumed 8250 GWh in 2008. In that year the electricity consumption of the residential, commercial and public services, agriculture/forestry and transport sector was 7165, 3908, 1303 and 1085 GWh, respectively (IEA, 2011i).

5.3.3 Greenhouse Gases Emissions

5.3.3.1 Energy Related CO_2 Emissions

Between 2000 and 2006 the CO_2 emissions from fuel combustion rose almost 35%; 5.2% per year to reach 39.8 million tons in 2006 (MEMME, 2009b). In 2006 the share of oil, coal and coal products, and natural gas on the emissions of CO_2 was, approximately, 61%, 34% and 3%, respectively (MEMME, 2009b).

The coal's share in the total CO_2 emissions in recent decades has increased, from 11% in 1980 to 34% in 2006. This upsurge is connected to the increase of coal consumption for power generation (MEMME, 2009b).

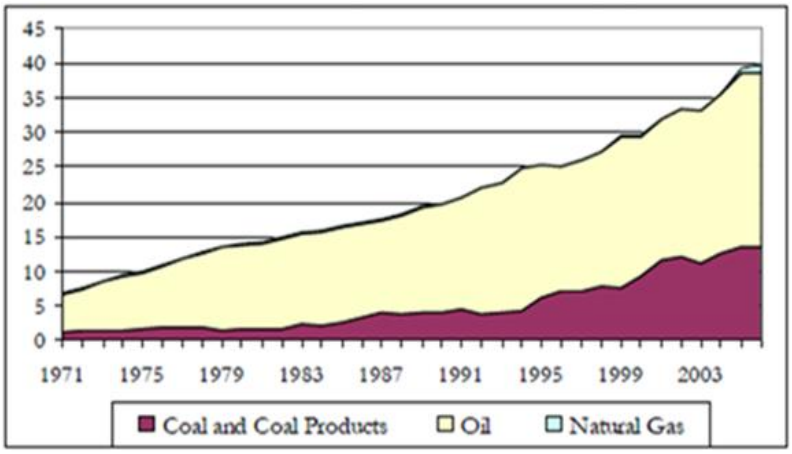


Figure 5-29 - CO_2 emissions from fuel combustion from 1971 to 2006 (Mt CO_2 per year) (MEMME, 2009b)

The bulk of all CO_2 emissions from fuel combustion came from three sectors, as illustrated in Figure 5-30: electricity and heat, transport and industry.

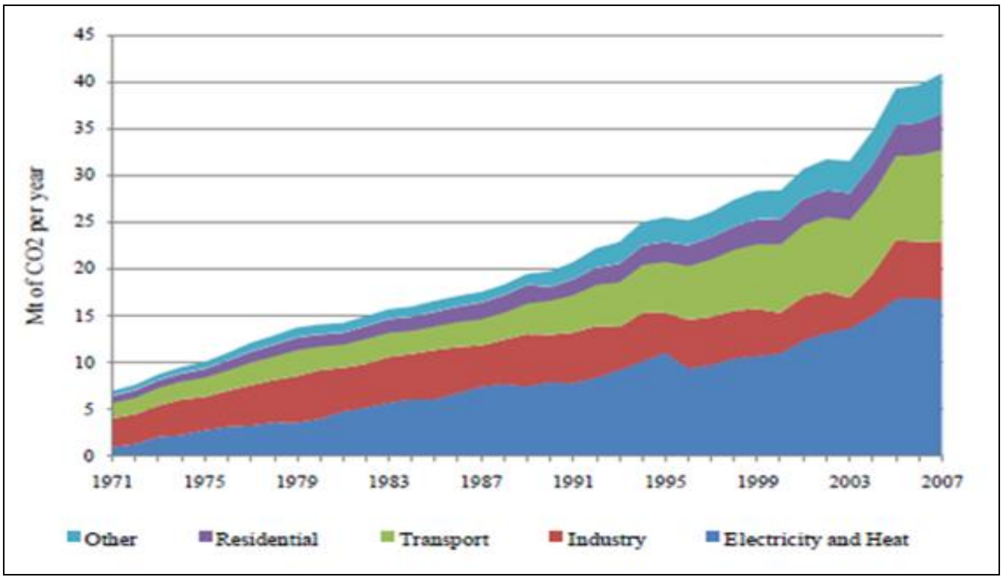


Figure 5-30 – CO_2 emissions by sector between 1971 and 2007 (MEMME, 2009b)

The electricity and heat sector is the largest source of energy-related CO_2 emissions. The CO_2 emissions from this sector have been rising substantially as a consequence of both sharp increases in demand and large continuous consumption of coal as the principal input fuel with a small share from RE sources (hydro and wind power). The transport sector is also very energy intensive and emits considerable CO_2 quantities. From 1971 to 2007 the transport sector CO_2 emissions, rose almost 500% and from 1997 to 2007 almost 50% which makes it the fastest-growing source of energy-related CO_2 emissions. In 2007, the CO_2 emissions from this sector represented 25% of the total. The industrial sector emits large amounts of CO_2 as well. Within this sector, the energy consumption and the CO_2 emissions are concentrated within the cement, phosphates and sugar units (MEMME, 2009b).

Between 1971 and 2007 the CO_2 emissions per capita almost tripled, going from 0.45 t per capita to 1.3 t per capita, respectively. In the same period, the country's CO_2 emissions per each unit of GDP increased almost 50% (MEMME, 2009b).

When compared against other countries, the CO_2 intensity of the Moroccan economy is above average. Although Morocco has a relatively low level of energy intensity (measured per GDP or per capita), its extensive consumption of coal means that the CO_2 emissions generated from each unit of energy produced and consumed are high (MEMME, 2009b).

In 2006, the Moroccan CO_2 emissions intensity was of 3.1 t CO_2/toe versus a world average of 2.4 t CO_2/toe. In the same year, for power generation, Moroccan CO_2 intensity was of 0.86 t CO_2/MWh versus a world average of 0.57 t CO_2/MWh. However, the per capita CO_2 emissions in Morocco were below world averages and below averages of all non-Annex 1 countries: in 2006, Morocco had emissions of about 1.31 tCO_2 per capita against the world's 4.28 tCO_2/capita and the 2.44 tCO_2/capita emissions of the non-Annex 1 countries (MEMME, 2009b).

In 2008 the CO_2 emissions from fuel combustion reached 42.09 Mt. Table 5-27 presents some key CO_2 emission indicators for 2008.

Table 5-27 - CO_2 emission indicators (2008) (IEA, 2011i)

CO_2/TPES (t CO_2/toe)	2.81
CO_2/capita (t CO_2/capita)	1.35
CO_2/GDP (kg CO_2/2000 USD)	0.76
CO_2/GDP (PPP) (kg CO_2/2000USD)	0.25

The CO_2 emissions upward trend is attributable to both population and GDP development and in some cases, superior shares of fossil fuels in the energy supply mix.

Figure 5-31 illustrates the different share of cement production, solid fuels, liquid fuels on carbon emissions and the total fossil fuel emissions in Morocco between 1989 and 2007.

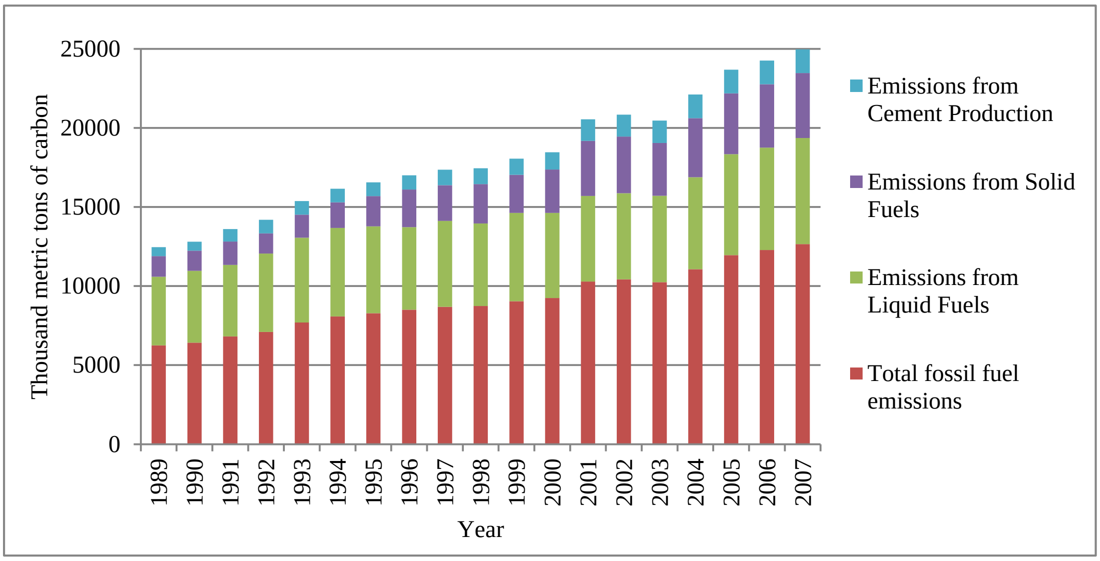


Figure 5-31 - Share of cement production, solid fuels, liquid fuels and the total fossil fuel emissions (CDIAC, 2011)

5.3.3.2 Methane, Nitrous oxide and PM10 Emissions

Figure 5-32 presents the methane emissions (stemming from human activities such as agriculture and from industrial methane production in kt of CO_2 equivalent) in Morocco.

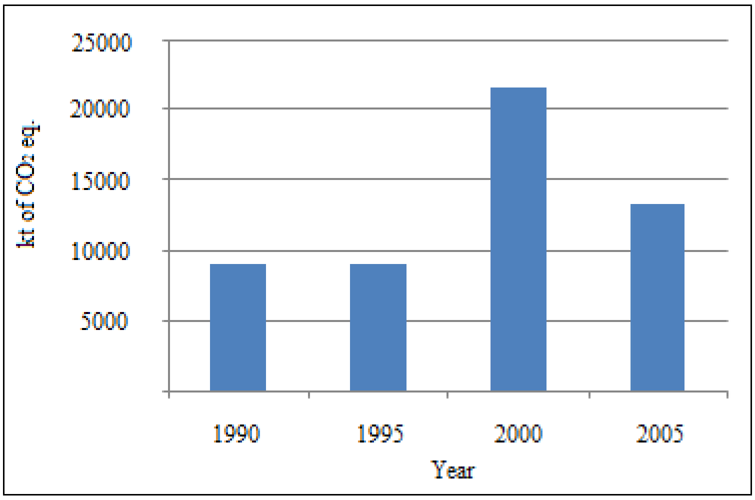


Figure 5-32 - Moroccan methane emissions (Trading Economics, 2011)

Figure 5-33 presents the agricultural methane emissions (includes emissions from animals, animal waste, rice production, agricultural waste burning non energy, on-site, and savannah burning) as % of the total methane emissions in Morocco. Figure 5-32 also illustrates the energy related methane emissions (from the handling, transmission, and combustion of fossil fuels and biofuels) as % of total in the country.

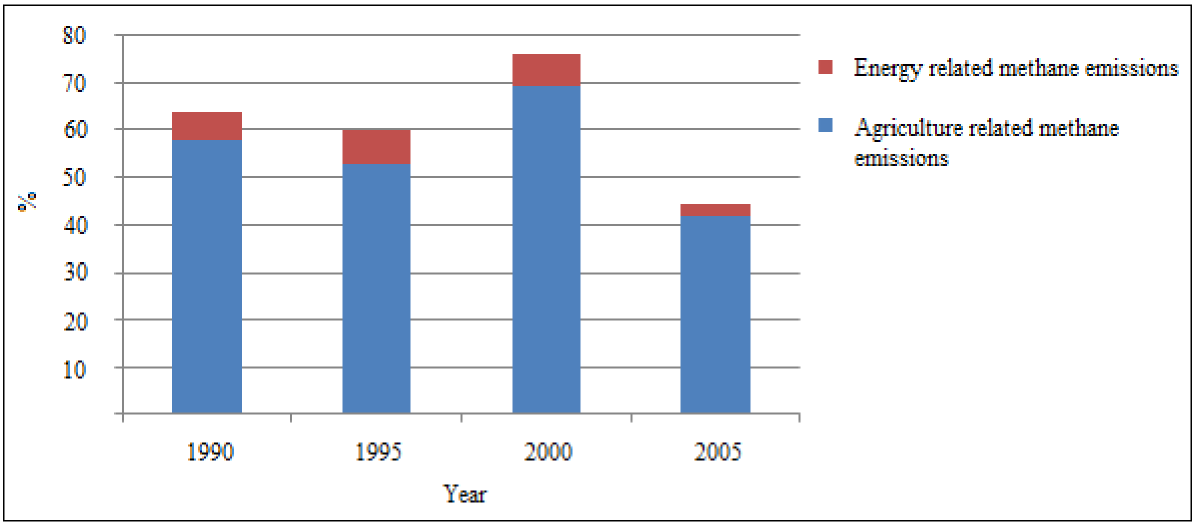


Figure 5-33 - Agricultural methane emissions as % of total (Trading Economics, 2011)

Figure 5-34 presents the nitrous oxide emissions (from agricultural biomass burning, industrial activities, and livestock management in thousand metric ton of CO_2 equivalent) in Morocco.

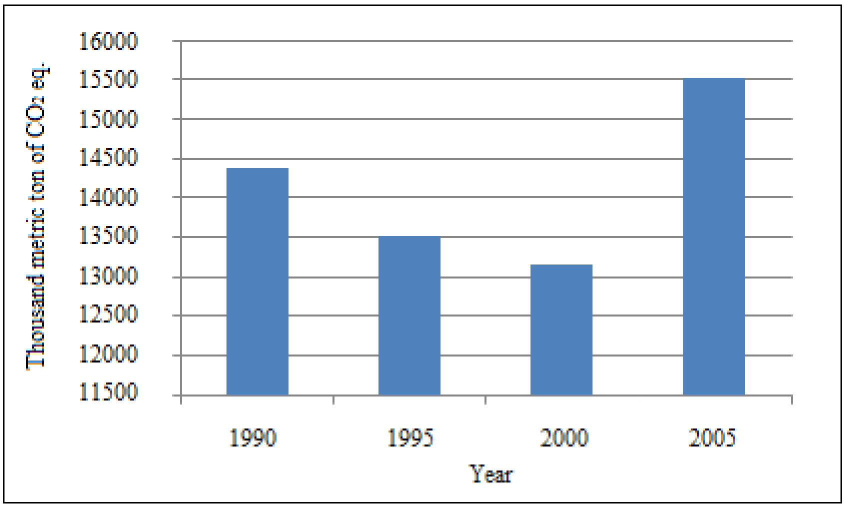


Figure 5-34 - Moroccan nitrous oxide emissions (Trading Economics, 2011)

Most of the nitrous oxide emissions come from fertilizer use (synthetic and animal manure), animal waste management, agricultural waste burning (non-energy, on-site) and savannah burning (Trading Economics, 2011).

In 1995, 10 thousand metric tons of CO_2 equivalent of other GHG emissions (by-product emissions of hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride) have been emitted in Morocco (Trading Economics, 2011).

Figure 5-35 presents historical data for PM10 country level (micrograms per cubic meter). The estimates represent the average annual exposure level of the average urban resident to outdoor particulate matter.

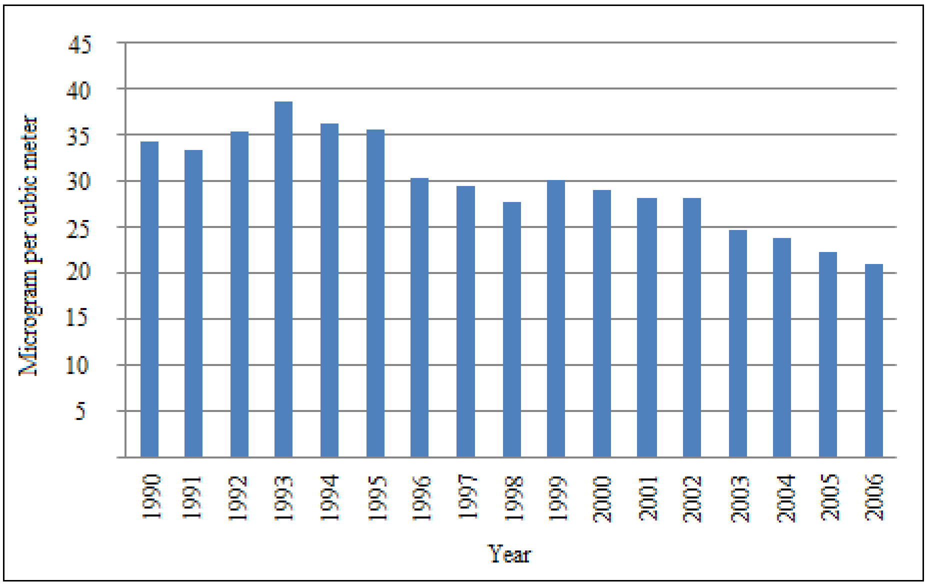


Figure 5-35 - Moroccan historical data for PM10 level (Trading Economics, 2011)

5.4 Energy Policies

The National Plan of Priority Actions (PNAP), currently underway, is the primary national strategy to pursue low carbon opportunities to achieve economic and social national objectives. The development of the PNAP was launched by His Majesty King Mohammed VI on April 15, 2008. The PNAP represents a holistic approach to the country's energy needs, seeking to enhance energy security and increase access, while at the same time lowering CO_2 emissions. In a great number of cases, the actions included (e.g., increase in renewable energy and energy conservation) achieve all goals simultaneously (MEMEE, 2008) (CIF, 2009). Key objectives of this ambitious national program include a 600% increase in wind power to reach 20% of power generation and a 15% reduction in energy use in buildings, industry and transport by 2020 (CIF, 2009).

The PNAP is a comprehensive national program representing the efforts and contributions of the ten major Ministries at the national level, among them: Ministry for Energy, Mines, Water and the Environment (MEMEE[14]), Ministry of Equipment and Transport, Ministry of Agriculture, and the Ministry of Industry, Commerce and New Technologies. It also holds formal partnerships with the ONE, ADEREE as well as local officials and municipalities. The PNAP procedures are to be implemented by 2012 (CIF, 2009).

By March 2009, the "New energy strategy" was adopted, aiming to provide sufficient and reliable energy to the economy and to the population as well as to prevent any harmful effect on the environment stemming from energy supply and uses (UNCCC, 2010). These goals rest on five strategic axes:

- Security of supply with diversification of fuel types and origins;
- Access and availability of energy for all segments of society at reasonable prices;
- Deployment of domestic energy sources, principally renewable, and the intensification of hydrocarbons exploration and oil shale valorisation;
- Promotion of energy efficiency; and
- Regional energy integration among the Euro-Mediterranean markets (UNCCC, 2010).

[14] The MEMEE is responsible for the development and implementation of government policy in the areas of energy, mines and geology and for the control of other sectors that depend on its authority.

5.4.1 Energy Players

The country's energy industry is composed of public and private players. The National Mines and Hydrocarbons Authority is the main public authority in the energy sector. This Authority resulted from the merger of the following different public entities:

- *Office National des Hydrocarbures et des Mines* (ONYHM);
- *Bureau de Recherches et de Participations Minières* (BPRM);
- *Office National de l'Electricité* (ONE);
- and the National Agency for Development of Renewable Energy and Energy Efficiency (ADEREE[15]), former *Centre de Développement des Energies Renouvelables* (CDER) (AGICI, 2011) (UNCTAD, 2011).

The main private companies operational in the energy field are:

- Moroccan Refining Company (SAMIR);
- Maghreb-Europe Gas Pipeline Management Company (METRAGAZ);
- Jorf Lasfar Energy Company (JLEC);
- Tahaddart Electricity Company (EET);
- Detroit Wind Energy Company (CED);
- LYDEC;
- REDAL; and
- AMENDIS (AGICI, 2011).

5.4.2 Market Structure

The oil and gas sectors are controlled by the National Office of Hydrocarbons and Mining (ONHYM), a state-owned company established in 2005. ONHYM is an independent financially autonomous public institution; its activities are supervised by the state to guarantee compliance with the Act of Parliament under with which it was created, principally with regard to its tasks and functions, and to ensure the application of the law (Law 33-01) and regulations relating to public institutions in general. ONHYM is subject to financial supervision by the state, as applicable to public institutions (ONHYM, 2011).

The Moroccan oil refinery (Mohammedia) is operated by SAMIR, which is owned by the Saudi company Corral Petroleum (OBG, 2011).

The country's power generation, was formerly exclusively operated by the state owned ONE. Since the late 1990s, some independent private producers (JLEC, EET and CED) contribute to the national electric generation by supplying the power exclusively to ONE through Power Purchase Agreements. The ONE is responsible for the power transmission. The power distribution is mainly run by the ONE and some private operators in the big cities of the country (LYDEC in Casablanca, REDAL in Rabat and AMENDIS in Tanger/Tetouan) (IAEA, 2010).

The Moroccan policy for power supply is drawn by the ONE and is submitted for approval to the Ministry of Energy, Mines, Water and Environment (IAEA, 2010).

[15] ADEREE aims to contribute to the implementation of government policy on renewable energy and energy efficiency.

5.4.3 Programs and Measures to Promote Renewable Energy

Since the creation, in the early 1980s, of the CDER, which is now ADEREE, Moroccan governments have shown determination to promote RE (UNCTAD, 2011).

Presently, the RE policy is in its generalized implementation stage with large renewable energy and energy efficiency programs, held by national and international institutions and banks (UNCTAD, 2011).

Morocco is developing RE with the objective to increase their share in the primary energy consumption to reach 12% in 2020 and more than 20% in 2030 (UNCCC, 2010). The country has the necessary resources to achieve these goals as its potential, mainly in solar and wind energy, is extensive and several strategies were drawn up to accelerate the implementation of utility-scale solar and wind projects (UNCCC, 2010).

A vast Solar Power Program was launched in 2009, with the objective to achieve 2000 MW by 2020 on five sites. The first 500 MW will be commissioned in 2015. This program is projected to prevent the emission of 3.7 million ton of CO_2 per year and avoid 1 million toe of fossil fuels and electricity imports. The total project investment is evaluated in 9 billion US dollars (UNCCC, 2010). Additionally, the country launched the Development Program of the Moroccan market for solar water heaters (PROMASOL) that includes the installation of 440000 m^2 and 1.7 million m^2 of thermal solar sensors in 2012 and in 2020 respectively. The thermal energy is projected to reach 1190 GWh/yr by 2020 and prevent the emission of 920 kton of CO_2/yr (AMDI, 2011).

To enhance the country's capacity to successfully implement the solar projects the government created, in January 2010, two new institutions: the Moroccan Agency for Solar Energy (*Agence Marocaine de l'Energie Solaire*, MASEN) with the aim of conducting feasibility studies on particular technologies; and the Energy Investments Company (*Société d'Investissements Energétiques*, SIE) with the purpose of attracting and finance profitable private energy projects (UNCCC, 2010).

Similarly, a Wind Power Program aiming to total 2000 MW by 2020 was launched. At present, 280 MW are provided by existing wind farms, 720 MW are under development and 1000 MW will be built on five new sites. The goal of this project is to avoid 5.6 ton of CO_2 emissions and 1.5 toe of energy imports. The whole cost of this project investment is estimated at 3.5 billion US dollars (UNCCC, 2010).

By 2020 the national installed capacity is projected to reach 14580 MW, according to the Minister of Energy, Mines, Water and Environment. Of this capacity, 42% is expected to be fulfilled by solar, wind and hydroelectricity, each representing 14%. Within the same period it is also projected that nuclear energy will contribute with about 7% of the installed capacity (UNCCC, 2010).

5.4.4 Programs and Measures to Promote Energy Efficiency

Energy efficiency is a key priority in Morocco's strategy to minimize energy dependency and ensure its optimal consumption. The country's goals are to perform energy savings between 12% and 15% in 2020 and to expand it 20% by 2030 (UNCCC, 2010).

In order to include energy efficiency in their regulatory frameworks, agreements were signed with the following strategic ministries: industry, transport, housing, agriculture, interior, and tourism along with regional bodies.

Action plans have been set up in all main sectors such as the promotion of:

- CHP and RE for power generation in industry;
- Assistance to tertiary and residential sectors to moderate electricity consumption;
- Improved modern public transportation and better management of urban traffic to lower personal vehicles use;

- Standardization and normalization to help consumers to purchase clean and efficient energy equipment;
- Efficient irrigation systems in agriculture, the use of biomass and solar energy for drying and refrigerating products to save energy and water;
- Awareness campaigns for the large public and specific users to encourage the use of lower energy consumption equipment and household appliances and to encourage public transportation use; and
- EE in building practices to enhance energy savings - Morocco has introduced a national program called "Energy Efficiency Codes in Residential Buildings and Energy Efficiency Improvement in Commercial and Hospital Buildings in Morocco". This project is run by ADEREE and other institutional partners. The objective of the program is to launch mandatory minimum energy efficiency performance requirements by means of a building code. This is expected to help the country bring its own laws and regulations in line. The project comprises the development of guidelines for technicians and professionals in hospitals, hotels, services, and housing companies for the integration of solar water systems. 32 health centers, 8 hospitals, and hotels have been selected to serve as example objectives (STW, 2011).

To boost the implementation of the former plans, the country launched favourable conditions to stimulate national and foreign investors and operators. For better visibility of individuals or companies investing in the country, attractive legislative and regulatory texts were launched or are being enacted. Particular laws concerning renewable energies and energy efficiency supported by the creation of dedicated Agencies has been promulgated. An Energy Development Funds with 1 billion US dollars capital was launched to support RE and EE projects (AMDI, 2011).

5.4.5 Climate Change

Morocco ratified the major international conventions on the environment. In 1992, Morocco joined the UN's Conference on Environment and Development (UNCED, the Rio de Janeiro summit), which lead to numerous major agreements such as the Rio Declaration on Environment and Development, the Agenda 21, the Convention on Biological Diversity and the UN's Framework Convention on Climate Change (UNFCCC), followed by the Johannesburg Summit in 2002 (OBG, 2011).

The kingdom was a signatory of UNFCCC in 1995 and of the Annex 2 of the Kyoto Protocol in 2002. Even though not obliged to reduce its carbon emissions, the country planned a legal framework to protect its environment and promote renewable energy and energy efficiency. The kingdom hosted the seventh Conference of the Parties in Marrakech (MEMEE, 2009) (OBG, 2011).

In 2001 Morocco published its first National Communication to the UNFCCC and in 2010 the country published the second National Communication.

Morocco introduced several climate change coping and mitigation mechanisms in many of its national plans as the reforestation of 50000 ha per year until 2014 (OBG, 2011).

The kingdom embraced the United Nations Clean Development Mechanism (CDM) as an opportunity to attract investments in cleaner technologies. The Moroccan CDM portfolio arose from the first mitigation assessments comprised in Morocco's First National Communication. These assessments led to the elaboration of a National Action Plan for the reduction of GHG emissions. From then on, the CDM portfolio has been improved and extended, within the framework of continuous and focused efforts. Morocco's National Action Plan takes into account 25 projects, in view of an estimated evolution of GHG emissions in the country by 2020. The Plan and the projects consider national policies, programs, and strategies, as well as Morocco's particular circumstance and conditions. The 25 projects were planned by Government departments, involved public and private institutions, or have been set out in close cooperation with their managerial staff and officers. In 2006, the CDM portfolio comprised many projects with significant potential for reducing GHG emissions focused on the promotion of energy efficiency and renewable energy, and on the reduction of energy waste (UNEP, 2011).

5.4.6 Sustainable Development

Since its participation in the Rio de Janeiro Earth Summit, the country has been in the process of implementing the recommendations of the United Nations Conference on Environment and Development. As part of the application of these recommendations in 1992 and within the context of global sustainability and human development initiatives, Morocco established a new strategy based on an integrated approach to development (UNCTAD, 2011).

By May 2003 Morocco introduced a law (Law 11-03) on the protection of the environment. This law provides general principles of national policy on environmental protection and among these principles is the integration of environmental concerns into all policies.

Along with the PNAP and the “New Energy Strategy” to provide sufficient and reliable energy to the economy and to the population as well as to prevent any harmful effect on the environment stemming from energy supply and uses, Morocco has introduced other development strategies to achieve its environmental goals, namely: the National Strategy for Environmental Protection and Sustainable Development, the implementation of the Plan for the Environment (PANE), the 2020 Strategy for rural Development, and the introduction of the National Initiative for Human Development (NIHD) (UNCTAD, 2011).

In 2009, determined to approach the challenges of protecting its environment, the kingdom drafted the National Charter for Environment and Sustainable Development (OBG, 2011) (UNCTAD, 2011).

6 Final Remarks

The future is naturally uncertain and always will be. Trends in economic growth (and therefore energy use and related emissions of CO_2) and technology development are difficult to predict. Still, concerns about energy security, the need to meet the predictable growing demand of energy and the threat of climate change, all pose major challenges to energy decision makers in Morocco.

One thing is certain: to reduce energy related CO_2 emissions worldwide and in Morocco specifically, there is no single solution; instead, a wide range of solutions is necessary and it will involve different choices by numerous stakeholders.

The IEA and the international community in general agree that Energy Efficiency improvements, the increase of Renewable Energy deployment, Nuclear Power and CCS technologies are central options within a portfolio to achieve the necessary sustainability targets in the most cost-effective way. In Morocco, all of these options are being considered, including CCS within the COMET project.

Even disregarding the output data provided from the TIMES modeling of the Moroccan energy system, it is possible to draw some general considerations - as to the CCS option for Morocco - based on the information collected to run the model itself. Such considerations will be discussed within the following paragraphs.

As by 2020 the national power installed capacity is projected to reach 14580 MW and 42% of this capacity is anticipated to be fulfilled by solar, wind and hydroelectricity, each representing 14%; and since it is also projected that nuclear energy will contribute with about 7% of the installed capacity;, this means that, in this scenario, fossil fuels and biomass will have to fulfill 51% of the installed capacity (Figure 6-1) and account for approximately 7436 MW in 2020 which corresponds to a 78% increase in the thermal installed capacity relatively to 2009 (4166 MW).

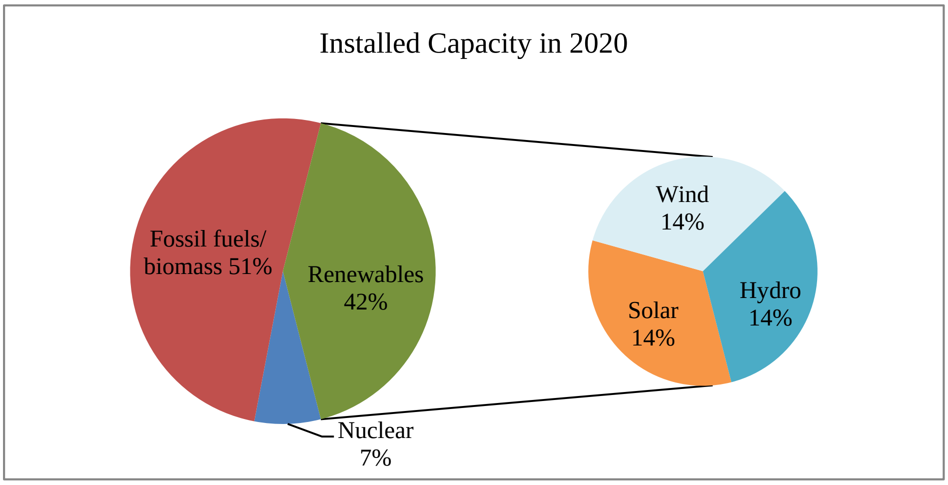


Figure 6-1– Projected installed capacity by 2020

In this scenario, the power sector in Morocco will continue to be highly dependent on fossil fuels. The perspective that the thermal installed capacity is to be substantially expanded within the following years and the fact that coal is expected to continue to be the primary fossil fuel for power generation in the next decades (according to the National Energy Strategy 2020-2030 published by the government in 2009) reinforces the necessity to consider CCS technologies for decarbonizing the power sector to some extent. This may imply the retrofitting of the existing units of the larger power plants like the Jorf Lasfar (JLEC) with CCS technologies, or the introduction of these technologies within the projected new units of Jorf Lasfar or within new facilities such as that of Safi.

Based on the information collected, within the industrial sector, the cement subsector also represents a significant opportunity for CCS deployment since the cement production is expected to grow 244% between 2010 and 2030 and that this is already the industrial largest source of CO_2 emissions in the country. Additionally, the IEA considers CCS technologies to be the main solution to achieve deep emission cuts within the cement industry.

Still, capturing CO_2 is an emerging technology within the power sector, not yet demonstrated on a commercial scale and CO_2 capture technologies for the cement industry are not likely to be commercially available before 2020, since, before then, further research and pilot tests are required to gain practical experience with these technologies, according to the IEA.

Yet, undoubtedly, if CCS technologies are to be part of the country's CO_2 emission reduction portfolio in the future - along with the projected EE improvements and further RE deployment - several challenges must be overcame in view of both the current CCS technologies intrinsic downsides (such as EE penalties, additional costs and the fact that these technologies are not entitled as CDM project activity) and the Moroccan circumstances.

For instance, if CCS technologies are to be deployed in the country:

- The fact that currently Morocco is not obliged to reduce its carbon emissions by any means suggests that the introduction of appropriate economic incentives such as tax treatment or other mechanisms are to play an extraordinary role;
- There is value in creating a regulatory, legal and accounting framework for CCS in Morocco, since at present there is no framework for regulating CCS projects in the country. Indeed, investments in these technologies will only occur if there are adequate financial incentives and/or regulatory mandates;
- Given the scale of investment required to deploy CCS, the country ought to foster international co-operation in order to decrease projects costs; and
- The Moroccan government should dedicate resources to disseminate information since public outreach is critical.

<u>MARKAL/TIMES outputs</u>

It is important to remark that to run the model several assumptions had to be made, owing to the unavailability of some important data and lack of time, which means that an ongoing process to collect data and improve the model is required for better insights.

On the supply side, missing input data includes, among others, detailed information on the actual available potential of biomass for power generation.

On the demand side, missing input data includes information on, among others:

- The number of houses with air conditioning;
- The number of square meters for commercial activities and this sector energy consumption by type of fuel;
- The energy consumption trend of the cement and phosphate industries as well as the type of fuel consumed by the different industrial activities; and
- Load curve profiles for several months.

After the submission of the input data, for the first modeling, important missing data has been identified. This data will be used to improve the model later in the project. It includes the following information:

- Wind technical potential (estimated to total 25000 MW);
- 200 feasible micro hydro power projects (ranging from 15 to 100 kW).

7 Conclusions

The energy demand in Morocco has rapidly increased over the last years. This upward trend is expected to continue in the coming decades, driven by a strong economic development and increasing population. As the energy demand is expected to grow, increasing concerns over energy security and environmental sustainability issues arise in Morocco. Indeed, it is estimated that by 2020, the primary energy and electricity consumption will double compared to their level in 2008 and that by 2030 these consumptions will be three and four times greater, respectively.

In the seventies the power sector depended on a considerable extent on hydroelectricity. However, from then on, the Moroccan power supply has been consistently heavily based on fossil fuels, and as there are limited fossil energy sources available within the country, Morocco is extremely dependent on energy imports and is the largest energy importer of North Africa. In 2008, the Moroccan net energy import amounted to 96%.

Alongside its energy demand growth, the CO_2 emissions from fossil fuels combustion have also increased. In fact, the Moroccan CO_2 emissions from fossil fuels combustion have more than doubled between 1995 and 2008 reaching, by then, 49.09 Mt.

Conversely to its fossil fuels unavailability, Morocco possesses substantial domestic unexploited Renewable Energy Sources, mainly solar and wind energy.

In order to sustain the on-going energy demand upsurge, decrease its exposure to international volatility commodity prices, improve its energy trade balance and reduce its energy related environmental impacts, Morocco has introduced several strategies in order to boost the deployment of Energy Efficiency measures within several sectors and increase the penetration of Renewable Energy within its energy supply portfolio.

National targets are to perform energy savings between 12% and 15% in 2020 and to expand it to 20% by 2030 as well as to increase the share of Renewables in the primary energy supply mix to reach 12% in 2020 and more than 20% in 2030. The Nuclear Power option is also being discussed by the Moroccan government as a future possibility for cleaner power generation.

The Moroccan thermal generation capacity is estimated to expand 78% until 2020, in relation to 2009 and coal is expected to continue to be the primary fossil fuel for power generation in the next decades. Within the industrial sector, the cement, phosphates and sugar units – the most energy and CO_2 emission intensive units in this sector – are expected to more than triple their energy use in 2030 in relation to 2005.

In view of such factors, it seems reasonable to at least consider debating the CCS option to decarbonise, on some extent in the future, the Moroccan power and industrial sectors. Will CCS - along with EE improvements, greater penetration of RES in the TPES - be a viable solution for Morocco within the future?

As it is known, advancing towards a low carbon future, in the most cost-effective way, requires a weighing of the different CO_2 abatement options available and a far-sighted approach. This means that the CCS option must be weighed against other carbon abatement options such as EE improvements, further RES penetration and nuclear deployment since each of these options entails a distinctive set of co-benefits, costs and risks that must be considered. Indeed, other things being equal, if one option is to bear a lighter burden, others will be required to do proportionately if Morocco is to effectively respond to the risks of climate change without compromising its economic development.

The COMET project - which goal is to study the techno-economic feasibility of integrating CO_2 transport and storage infrastructures in the West Mediterranean region – will provide some insights concerning the possibility of deploying CCS technologies in Morocco in the future in an integrated approach.

In view of the COMET project, one thing is acknowledge beforehand: a CCS integrated approach, compared to a standalone CCS project in one of the three countries involved, implicates interoperability issues but results in economic advantages and other benefits.

8 Future Work

As previously stated, to run the model, several assumptions have been made, owing to the unavailability of some important data and lack of time due to COMET project commitments. Therefore, within the context of the COMET project and the modeling of the Moroccan energy system, future work includes the gathering and introduction of important missing input data in order to improve the model so as to better weigh alternative courses of actions in an integrated approach.

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